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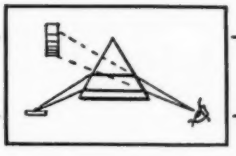

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THE OPTICAL SOCIETY OF AMERICA was organized in 1916 "*to increase and diffuse the knowledge of optics in all its branches, pure and applied, to promote the mutual interests of investigators of optical problems, of designers, manufacturers and users of optical instruments and apparatus of all kinds and to encourage cooperation among them.*" It aims to serve the interests of all who are engaged in any branch of optics from fundamental research to the manufacture of optical goods.

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Editorial Comment

RESEARCH AND PUBLICATION

FREEDOM to publish the results of his investigations is one of the most cherished possessions of the scientist. A young man entering an academic career finds free publication assured, as a natural privilege of the scholar. If he enters research in industry, however, he is likely to encounter a different situation. Some corporations which support and are supported by research laboratories have liberal policies in regard to publication, but there are still far too many which treat all results of research as professional secrets.

That such suppression of information is short-sighted even from a selfish standpoint is suggested by the close correlation which is found to exist between a liberal publication policy and commercial success. How the liberal policy is related to the success may well be argued; all evidence points, however, to the fact that any company which depends on research to a marked degree will do well to follow such a policy. Eminent directors of research agree that no company has ever been injured by liberality in sharing information. Even solutions of specific problems for which an industry as a whole is waiting are found to redound most to the benefit of the company when made public. The reason for this is not far to seek—as the volume of a sphere increases faster than its radius, so the value of new information increases most rapidly when taken in conjunction with other information.

But what of the firm whose managers, while recognizing this fact, attempt to capitalize on it by encouraging others to publish while they maintain an over-secretive policy? On such there are several automatic checks. One such check arises from the fact that most industries are to some extent dependent on the colleges for new men. Professors are naturally interested in guiding their better graduates into firms which are forward-looking, cooperative, and genuinely interested in the development of science as a tool for economic welfare. When instances of short-sighted publication policy become known the colleges are likely to steer their better men elsewhere, and the offending companies soon find themselves forced to pay higher salaries for less able men.

So real is this effect that a number of industrial research laboratories and government bureaus are finding it wise to permit their scientific investigators to devote a fraction of their time to fundamental research, since by so doing they can attract workers of greater ability.

Research laboratories probably cannot be supported effectively by firms of less than a certain size, for the same reason that a steam boiler cannot be operated economically on an automobile. Such companies should turn for aid to some of the numerous consulting services, or to the divisions of industrial cooperation of the colleges. Once a firm has been fortunate enough to attain locomotive stature, however, all the evidence indicates that it will pick up speed faster if it allows the components of its engine to blow off a bit of steam now and then.

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Vectographs: Images in Terms of Vectorial Inequality and Their Application in Three-Dimensional Representation

EDWIN H. LAND
Polaroid Corporation, Boston, Massachusetts
(Received May 11, 1940)

THE light emerging from a sheet of polarizing material of the modern type may be regarded as a vectorial field in which the vector assigned any point is substantially equal in magnitude and direction to the vector assigned to every point on the surface. The vector is the electric vector of the polarized portion of the emergent beam. Insofar as the vectors are parallel, and have the same length and sense, they comply with the definition of vectorial equality. One optical objective in the manufacture of polarizing sheeting has been to achieve equality in vectorial magnitude and direction for all points on the surface and for an adequate range of frequencies.

The purpose of this paper and others to be published later is to discuss the valuable properties of a *controlledly non-uniform* vectorial field created with or in polarizing surfaces. This new kind of field when it forms an image will be termed a vectograph; thus a vectograph is an image rendered in terms of vectorial inequality. This inequality may derive from (a) variation in length of the vector, or (b) variation in its direction. The variation in length may be merely a function of location on the surface of the point to which the vector is assigned, or it may be a function of frequency, or of position and frequency. The variation in direction may also be a function of position and frequency. Furthermore it will be shown that the variation in length can be translated into variation in direction, and that this translation provides an important tool for control of vectorial direction. The present article will consider those images in terms of vectorial inequality for which the inequality resides in differences in length rather than in non-parallelism, and in which the length varies with position but is substantially constant as a function of frequency for the frequency range in the visible spectrum.

The vectograph promises to have numerous practical applications in optics, the most dramatic of which is three-dimensional representation. Before these applications are considered, a brief introductory survey of the geometry of the vectograph will be given, the detailed analysis to follow in a later paper.

In Fig. 1, case *A* is the luminous field produced by the passage of a beam of ordinary light through an ideal polarizer. Here the vectors are equal, being collinear, and parallel to a principal direction of the polarizer. The degree of polarization *V*, which is equal to the ratio of intensity of polarized light leaving the polarizer to the intensity of total light leaving the polarizer, is equal to unity. The intensity of the emergent light is half the intensity of the incident light.

Case *B* is the first type of vectographic field. The degree of polarization of the rays emerging from the sheet is a function of x and y and is in general less than unity. The vectors are collinear and parallel but vary in magnitude as the degree of polarization varies from zero to unity. The total intensity of the emergent light varies from (nearly) that of the incident unpolarized light to half that value. This type of vectograph is perhaps the most fundamental one since the polarizer producing it can be prepared by the methods now used in the graphic arts, such as photography and halftone printing.

Case *C* is the vectograph produced by passing ordinary light through the combination of the polarizer that produced the vectograph in case *B* and the perfect polarizer in case *A*. The vectographic field in case *C* comprises vectors, all of which are parallel, and which are collinear with the principal direction of the perfect polarizer. The degree of polarization is unity and it is the variation in the magnitude of the vector that defines the image. Case *C* is of immediate practical importance because when θ is variable it provides a method of continuous control of contrast in a vectographic image; and when θ is 90° or 0° case *C* is the basis of the system of three-dimensional representation.

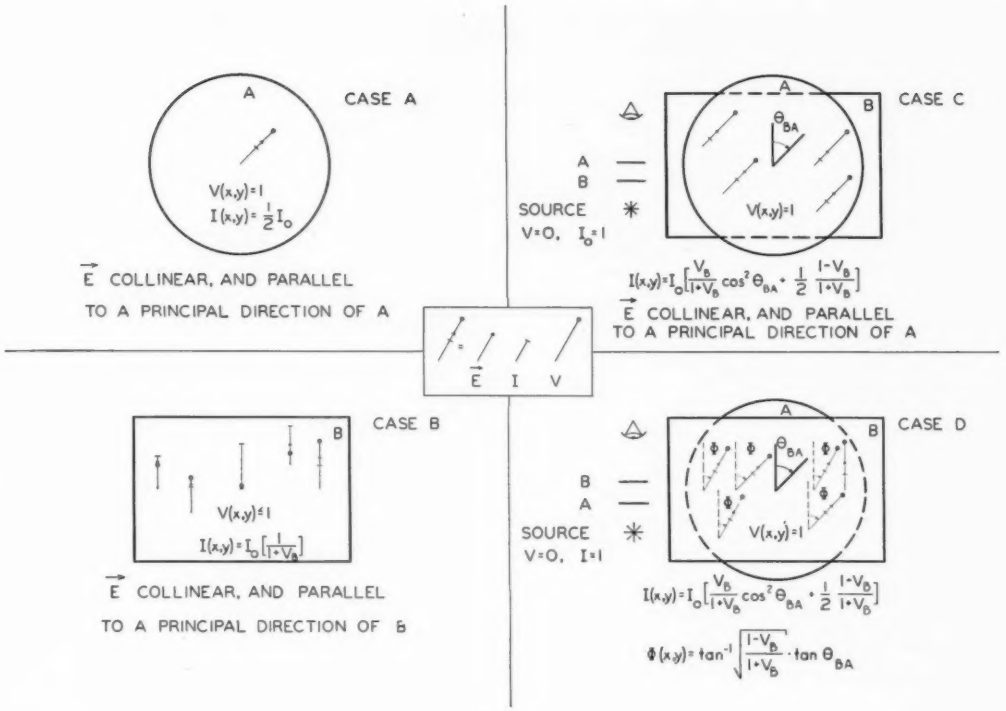

FIG. 1.

From an optical point of view, perhaps the most interesting is case *D*, because it describes a method of translating vectorial magnitudes in a collinear system, which can be produced photographically, into variation in vectorial direction. Case *D* is the vectorial field produced by the polarizers in case *C* arranged in reverse order. The plane-polarized light from the perfect polarizer passes through a partial polarizer (which is assumed to have negligible birefringent retardation) the principal direction of which makes an angle, θ, with that of the perfect polarizer. The incident linearly polarized light emerges as linearly polarized light with its direction of vibration, $\varphi_{(x,y)}$, a function of V and θ. It will be shown in a later paper that this type of field can be used for producing an image which, when examined with an analyzer, can have its contrast not merely varied but even reversed so that positives may be converted to negatives and negatives to positives. It will also be shown that important results can be produced by having V a function of quantities other than x and y.

It is noteworthy that for the purpose of analyzing the result of combining a partial polarizer with a total polarizer in either order, one need use only two variables: θ=angle between the preferred directions of the polarizers, and V=degree of polarization of the sheet. The properties of the polarizer are specified only if the restriction is added that the ratio describing V, for the polarizer, is taken when all the incident light falling on it is unpolarized. In analyzing the four cases, *A*, *B*, *C*, and *D*, we add the further restriction that the polarizers do not absorb energy from a beam of linearly polarized light which falls on it, when the vector representing the direction of polarization is collinear with the preferred direction of the polarizers.

PREPARATION OF A VECTOGRAPH

In order to make the kind of polarizer used in case *B* easier for the reader to visualize, the preparation of such a polarizing surface from a photograph will be described before proceeding with further discussion of optical properties.

Only one process will be described because the variety of methods that have been developed for preparing vectographic polarizers is essentially chemical and outside the scope of this article.

A very thin polarizing surface, uniform both in density and orientation, is prepared by orienting a concentrated suspension, in a plastic, of submicroscopic dichroic crystals on a surface of a sheet of glass or plastic. To this polarizing surface there is then transferred a resist of gelatin in which the desired photographic image exists as variations of thickness or as variations in hardness. The composite sheet is then subjected to a fluid reagent which acts through the resist to decrease the polarization of the polarizing layer, thereby forming in it an image in terms of degree of polarization.

The Vectograph for the Photographic Image and Its Use for Control of Contrast

The image in terms of degree of polarization formed by the above process appears, as indicated in case *B*, as a faint image of low contrast. It is apparent from the equation

$$I_{(x,y)} = I_0\left[\frac{1}{1+V_B}\right]$$

that the intensity of the emergent light can vary only between the limits I_0, the full intensity of the incident light, and $\frac{1}{2}I_0$. In terms of photographic density, this range from 0 to 0.3, is too small to be generally useful. When a "perfect" polarizer is employed over the vectographic polarizer in case *B* (as in *C*), or under the polarizer in case *B* (as in *D*), the density increases as the angle θ increases. This increase in density is more rapid for high densities than for low, but the density reproduction approaches linearity over a long range of densities as θ approaches 90°. These density changes are graphically indicated in Fig. 2. The density of the vectographic sheet is calculated from the intensity formula in Fig. 1, case *C*:

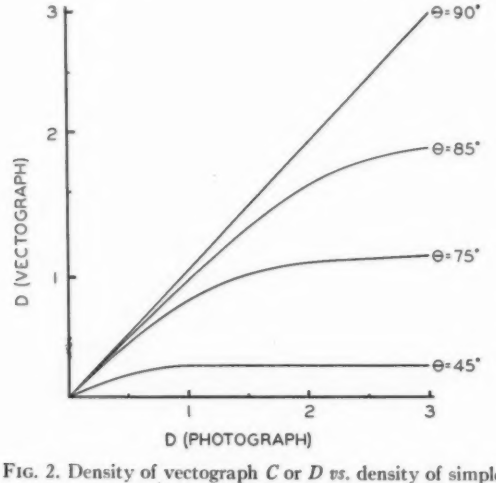

Fig. 2. Density of vectograph *C* or *D* *vs.* density of simple photograph. θ = constant.

Density of vectograph

$$\text{(a)}\quad D=\log_{10}\left[\frac{I_0}{I_{(x,y)}}\right]$$

$$=-\log_{10}\left[\frac{V_B}{1+V_B}\cos^2\theta+\frac{1}{2}\frac{1-V_B}{1+V_B}\right],$$

$$\text{(b)}\quad \text{but}\qquad V_B=\frac{1-10^{-D_p}}{1+10^{-D_p}},$$

where D_p, density of a corresponding silver image, is assumed equal to the density, with respect to the absorbed component, of the polarizing material in the vectographic polarizer, in case *B*.

Substituting (b) in (a) above,

$$D=D_p-\log_{10}\left[1+(10^{D_p}-1)\cos^2\theta\right]+\log_{10}2.$$

It is convenient for comparing these densities to assume that the world is seen through an analyzer, thus dropping the log 2 and shifting the axis by 0.3,

$$\text{(c)}\qquad D_v=D_p-\log_{10}\left[1+(10^{D_p}-1)\cos^2\theta\right].$$

By plotting this equation, D_v *vs.* D_p for various values of θ constant, the curves shown in Fig. 2 are derived.

The series of photographs, Figs. 3, 4, 5 and 6, show successive changes in contrast as the complete polarizer (here the small rectangle) is rotated superposed on the vectographic polarizer. The usefulness of the nonlinear curves in Fig. 2 with relation to the *H* and *D* curve of the photographic negative will not be discussed here. The straight line shown for $\theta=90°$ is assumed, but does correspond remarkably well with the results

FIG. 3. Vectographic print in ordinary light without analyzer. Case *B*.

FIG. 4. Vectographic print with polarizer or analyzer, case *C* or case *D*, with $\theta=0°$.

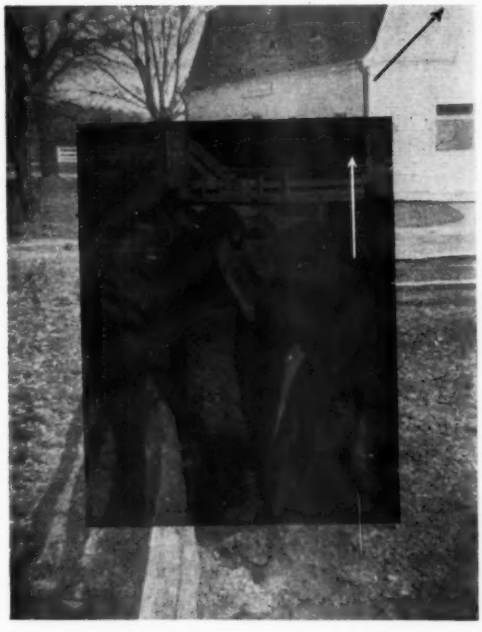

FIG. 5. Same as Fig. 4 but with $\theta=45°$.

FIG. 6. Same as Fig. 4 but with $\theta=90°$.

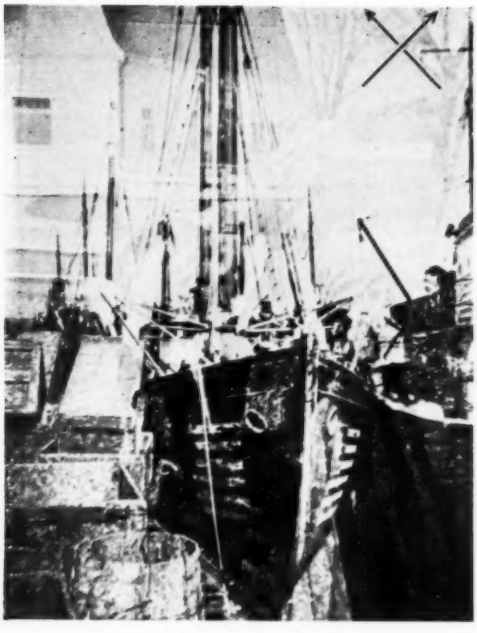

FIG. 7. Superposed vectographic prints of horse and boat, with axes crossed and without analyzer or polarizer.

FIG. 8. Analyzer rotated to produce full contrast in horse picture and zero contrast in boat picture.

FIG. 9. Analyzer rotated to produce full contrast in boat picture and zero contrast in horse picture.

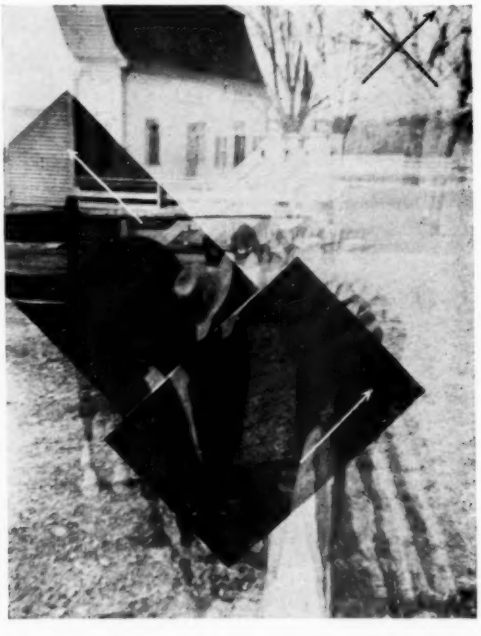

FIG. 10. Stereoscopic pair, part of which is covered with analyzer to show right eye picture, the other analyzer being rotated to show left eye picture.

obtained in the actual reproduction of vectographic films. In practice the darkness of the shadows and the lightness of the highlights depend on the value of the dichroic ratio of the polarizing material in which the image is formed. The polarizers which have been developed for this purpose have extremely high dichroic ratios.

Because of the colloidal size of the polarizing particles, the image can be grainless for light in the visible spectrum and because the polarizing surface is extremely thin, continuous images with good definition can be formed in the vectographic film. This definition combined with the long linear density scale makes the vectographic image suitable for photographic reproduction.

Superposed Vectographs

From the popular if not from the scientific point of view, the most impressive properties of polarizers which form vectographic images are those acquired when the two partial polarizing sheets are superposed with their preferred directions at 90°. The photograph, Fig. 7, is such a vectograph, consisting of an image of a boat and an image of a boy with a horse. The vibration direction for one of the images is 45° clockwise and for the other 45° counterclockwise. Fig. 8 shows an analyzer so oriented that the horse picture has its maximum contrast and the boat picture zero contrast. Fig. 9 shows the analyzer so oriented that underneath it the boat picture has its maximum contrast and the horse picture zero contrast. If an observer regards the vectograph photographed in Fig. 7 with spectacles, the left eye of which is an analyzer oriented as in Fig. 8 and the right eye of which is an analyzer oriented as in Fig. 9, then one eye will see the horse and the other eye the boat. Each image is complete and continuous and none of the information that it contains is in anyway suppressed by the existence of the other superposed image.

Each vectograph is in itself a partial analyzer for the other and to some extent renders visible the contrast in it. Fig. 10 shows a three-dimensional print. It will be seen that considerable contrast is already apparent in each picture, even in the region where there is no analyzer. If the polarization axes are at 90°, this contrast, created in one picture by the other, is less than the contrast which can be introduced by the analyzer, and does not alter the proper contrast introduced by the analyzer. While this follows from the point of view implicit in Fig. 1, it may be helpful to consider another point of view. A dichroic polarizer violates the exponential law for ordinary light and possesses a rapidly decreasing absorption coefficient as a function of the number of oriented molecules traversed by the light. That vectographic polarizer with axis parallel to the axis of the analyzer may be regarded as a continuation of it, having negligible absorption even where its percentage polarization is high and, therefore, negligible absorption everywhere.

Some Uses of Superposed Vectographs Other Than for Three-Dimensional Representation

Superposed vectographic images afford a convenient method for permanently recording pairs of pictures or diagrams that are to be related to each other; for example, a blueprint of a machine and the finished machine to the same scale can be recorded on the same print or slide and one faded into the other as desired. Astronomical observations can be made at different times and recorded on the same surface so that by rapid rotation of the analyzer small changes can be observed. In general superposed vectographs form a permanent record for the type of work previously done with the blink stereoscope. (It is to be hoped that this apotheosis of the "before and after" picture will serve science as much as advertising.)

Vectographs for three-dimensional representation

Superposed vectographs seem to be an ideal solution for the classical problem of overlapping the left and right eye plane intercepts of the rays from the object to be represented. The left and right eye images are rendered as two vectographs, with the axis of polarization of one crossed with the axis of the other. The three-dimensional print consists of these two vectographs superposed. The observer wears viewers in which the analyzers have their axes set in correspondence with the images. It is interesting to note that for the stereoscopic pictures projected

with polarized light prior to the use of vectographs, the analyzer at the right eye was oriented with its transmission axis *parallel* to the direction of vibration of the light forming the right eye image. For vectographs, the analyzer at the right eye has its transmission axis *crossed* with the direction of vibration of the light forming the right eye image. The blacks are formed by the viewing analyzer in the spectacles; the whites are seen because they are not polarized.

The form that the vectographic sheets take depends, of course, on the purpose. The method is suitable for transparencies, such as slides and motion picture film, and for prints.

Projection

When vectographs are used for projection, one component of the light is used for the left eye image and the other component for the right eye image. Consequently, stereoscopic projection can be accomplished with a single projector and at least as much light obtained from this single projector with a given lumen output as from previous stereoscopic methods employing two projectors each having that same lumen output. Of course, no attachments are necessary since the vectographic images are by definition self-polarizing. If, instead of vertical and horizontal polarizing axes, axes at 45° to the horizontal are chosen, then reversal of the slide for left and right sides also results in giving the left eye picture to the right eye and vice versa. Thus a vectographic slide can be reversed without becoming pseudoscopic. (It can be made pseudoscopic by being shown upside down or by turning the viewing analyzer upside down.) Vectographic slides have a number of practical advantages. Superscriptions written on the surface of the composite image will appear when projected to be on the plane of the screen. Similarly dirt-spots will not produce retinal rivalry and will simply appear as dirt-spots on the plane of the screen, with acceptable spatial relation to the image. Finally these slides can be filed in the ordinary filing system and shown interchangeably with the ordinary slides.

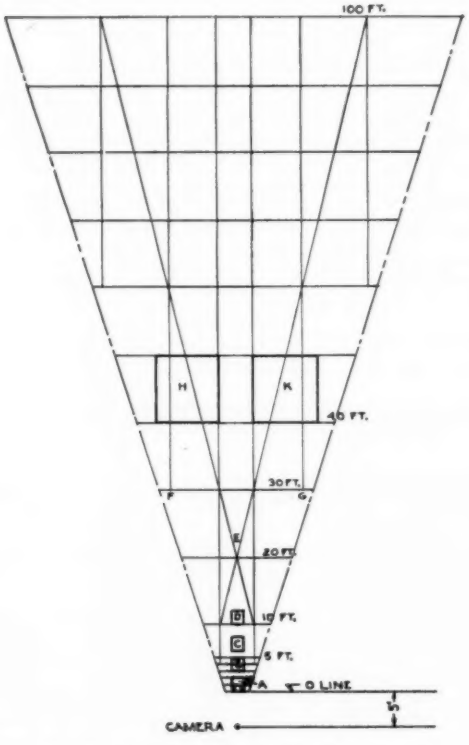

FIG. 11. Plan view of scene taken by camera. Scale 1/330 actual size.

Prints for direct viewing

Although vectographic transparencies for projection promise to have great practical importance, the most impressive immediate application of the vectograph appears to be in prints for direct viewing. There is no theoretical limit on size and very small as well as very large prints can be made. The layers in the present type of print are as follows: (1) paper, (2) suspension of aluminum flake, (3) right eye vectograph image, (4) left eye vectograph image, (5) hard waterproof varnish. All these layers are, of course, bonded together and the print appears to the naked eye to be a slightly blurred photograph (Fig. 10) of the ordinary type except for the metallic look of the aluminum flake backing. This metallic look vanishes when the viewers are used.

Because of the general desirability of prints of small size, it was considered worthwhile to initiate a more extensive investigation of the nature of the space representation given by any small stereoscopic picture taken with full interocular. This program is being undertaken by

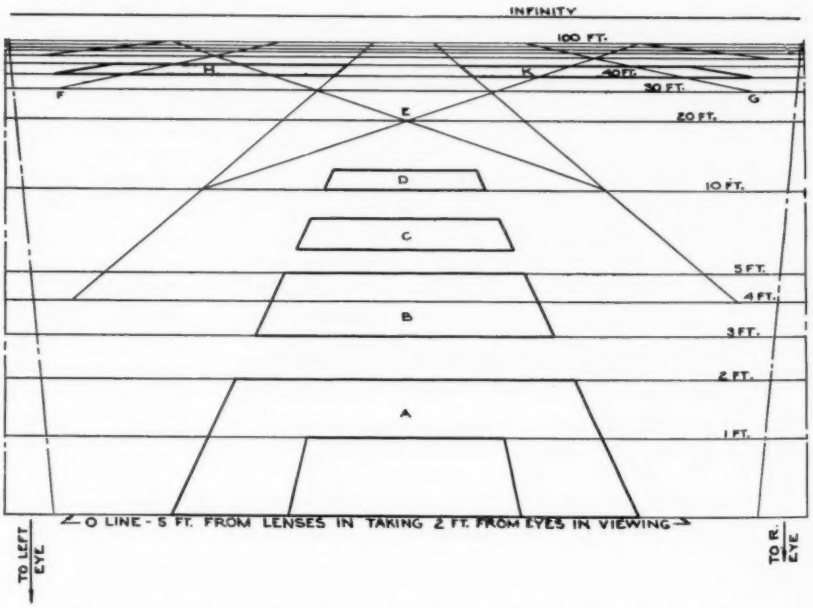

FIG. 12. Plan view of stereoscopic image of scene in Fig. 11. Scale = 1.8×actual size. f. 3.5 in.; P 2 ft.; d_0 5 ft.

Professor John T. Rule, of Massachusetts Institute of Technology. He has kindly prepared two plan views for this paper. Fig. 11 is a plan view of the space before the camera. Fig. 12 is a plan view of the space represented in the space reproduction. Fig. 13 shows the depth of the image in inches plotted against the depth of the scene in feet.

Figure 12 is drawn with the following mounting procedure in mind. The forward points of the scene are superimposed to prevent any point in the image from being in front of the plane of the print and to establish the frame of the print in the frame of the nearest point. It is interesting to note that the maximum possible synthetic depth for this small print is only a few inches and that 90 percent of the apparent depth of the print occurs in the first 50 feet of the scene. In spite of the strange appearance of Fig. 12, it has been our experience in the time that these prints have been available that they are at least as satisfying, if not more satisfying, than any other form of three-dimensional representation. The experience of seeing them seems to be entirely different from that of seeing an undistorted space synthesis on a large screen, which is satisfying in quite a different way. It would appear that life-long training in looking at ordinary monocular small prints has prepared us for the new kind of abstraction constituted by the small three-dimensional vectographs.

THREE-DIMENSIONAL VECTOGRAPHS IN NATURAL COLOR

Effective three-dimensional vectographs in natural color have been prepared. The theory of

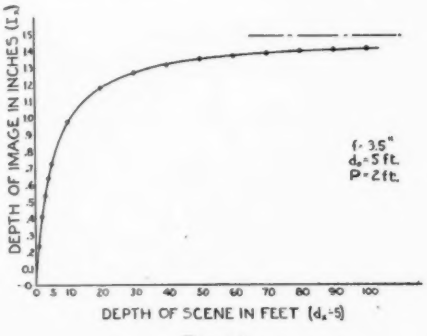

FIG. 13.

these will be given in a subsequent paper on vectographic fields.

Acknowledgments

The development of the concepts inherent in the vectograph, and of the materials and processes used in preparation of vectographic fields, is the result of the organized activity of a group in the Research Division of Polaroid Corporation. In this group Mr. Joseph Mahler has been the most active worker. His early conception of the effectiveness of this kind of three-dimensional print, and his intuitive skill in using new processes, are responsible to a large degree for the progress of this development. Grateful acknowledgment is made to Dr. C. D. West, Howard G. Rogers, William H. Ryan, F. J. Binda and to the many others who have made valuable contributions.

The Nerve Messages in the Fibers of the Visual Pathway*

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(Received February 26, 1940)

PRESENT-DAY methods make it possible to detect and record the activity produced in the fibers of the optic nerve in response to illumination of the eye. Thus the signals which are sent by the photoreceptor cells to the nerve centers may be intercepted, and, since it is possible to register the responses in single nerve fibers, the activity of the individual cellular units under different conditions may be investigated. In addition to providing information regarding the actual sensory data that are supplied to the visual centers of the nervous system, this method makes possible an objective study of the mechanisms whereby the visual sense cell translates light into nervous activity.

The disturbance which is set up in a nerve fiber when it is stimulated,[1,2] and which spreads as a wave from the point of stimulation, consists of an alteration in the molecular structure of the living tissue—an active response of each element of length of the fiber. Chemical reactions take place, and physical changes can be detected in the fiber as this wave of activity is propagated along its length. One of the physical accompaniments of this alteration in structure is a change in the electric potential of the point which is actively responding, measured with respect to an adjacent, as yet inactive, point on the fiber. It is the commonly accepted view that the local electric currents resulting from this difference in potential are directly responsible for the excitation of the region of the nerve fiber just ahead of the advancing wave front of the propagated disturbance. The fluctuation in the potential of a given point on the nerve fiber, due to the passage of such a propagated disturbance, can be recorded by any device capable of registering small, rapid voltage fluctuations. By this method the activity in the fibers of the optic nerve has been studied.

Oscillograms of the electrical activity in an optic nerve fiber,[3] resulting from steady illumination of the eye, are shown in Fig. 1. An eye of a king-crab (*Limulus*) was removed from the animal with about one centimeter of its attached optic nerve. A small bundle of fibers dissected from the nerve was slung over two electrodes (chlorided silver wires) connected to the input of an amplifier; this bundle was split successively, until only a single active nerve fiber remained. Illumination of the eye then stimulated the sensory cell attached to this nerve fiber, and the resulting activity in the fiber was recorded by means of an oscillograph in the output of the amplifier.

The regular succession of uniform electrical fluctuations shown in Fig. 1 is typical of the activity of a sensory nerve fiber whose receptor element is subjected to steady stimulation.[1] Each deflection is the electrical sign of the passage of a propagated disturbance, or "nerve impulse," past the electrodes on which the fiber was slung. It is a fundamental characteristic of nervous action that a propagated disturbance always involves the maximum change of which

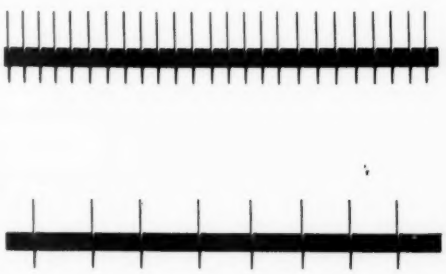

FIG. 1. Oscillograms of the amplified potential changes in a single optic nerve fiber (eye of *Limulus*) due to steady illumination of the eye. Intensity of illumination is ten times greater for upper record than for lower. Nerve fiber slung over two chlorided silver wires connected to input of condenser-coupled amplifier (time constant = 0.1 sec.). Recording by General Electric Company Duddell type oscillograph. Deflection upwards denotes negativity of electrode nearest the eye. Magnitude of deflections *ca.* 1 mv. Full length of each record corresponds to 1 second.

* Presented at the Optical Society of America Symposium on Optics of Vision, Lake Placid, New York, October 13, 1939.

[1] E. D. Adrian, *The Mechanism of Nervous Action* (University of Pennsylvania Press, Philadelphia, 1932).

[2] D. W. Bronk, Trans. and Studies, College of Physicians of Philadelphia, [4], **6**, 102 (1938).

[3] H. K. Hartline and C. H. Graham, J. Cell. and Comp. Physiol. **1**, 277 (1932).

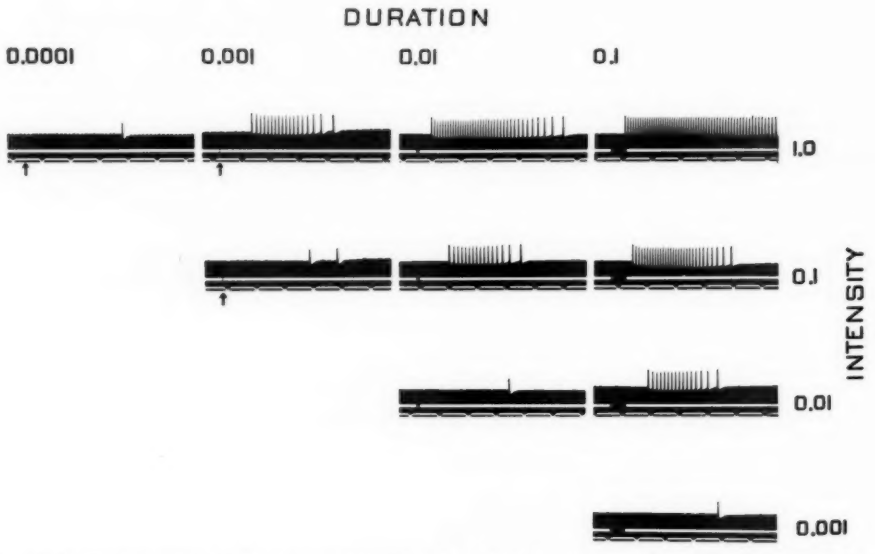

FIG. 2. Oscillograms showing the bursts of impulses in a single optic nerve fiber (*Limulus*) in response to short flashes of light of various intensities and durations. Relative intensity for each horizontal row given on right ($1.0 = 3 \times 10^6$ meter-candles). Duration of flash for each vertical column given at top, in seconds. Signal of light flash blackens the white line above the time marker (arrows mark position of signal for the very short flashes). Time marked in $\frac{1}{5}$ second (from Hartline, 1934).

the fiber is capable, at each point along its length. This is the reason for the uniformity of the individual deflections in Fig. 1. After each disturbance, a certain amount of time is required for the fiber to recover its ability to respond. Then, if the stimulus is still acting upon the receptor, another impulse will be initiated and conducted in the nerve fiber. Thus the periodicity of the nerve activity is due to a form of relaxation oscillation. The frequency of the oscillations depends upon the intensity of the stimulus, since a strong stimulus is able to recycle the system in a brief interval, while a stimulus of low intensity is unable to initiate the next impulse in the series until the tissue has more nearly recovered. Thus in the experiment shown in Fig. 1 the frequency of nerve impulses was higher when the eye was strongly illuminated (upper trace) than when the intensity of illumination was only one-tenth as great (lower trace).

The analysis of the processes taking place in the visual sense cell, from the first action of light upon the substance of the receptor element to the final initiation of nerve impulses in its attached fiber, constitutes a fundamental problem of visual physiology. This problem may be attacked directly, by investigating the properties of the single visual sense cell under various conditions, using the discharge of impulses in its attached nerve fiber as a measure of its activity. It is profitable to begin with a study of the responses to short flashes of light.

In Fig. 2 are records of the impulses discharged in a single optic nerve fiber in response to flashes of light of various intensities and durations.[4] It is to be noted, first of all, that the entire discharge of impulses in response to a short flash takes place after the flash is over. A brief flash can therefore produce a change in the sense cell which persists, causing a discharge of impulses which begins after an appreciable latency and which may last for several seconds. The degree of this activity—the total number of impulses elicited and the frequency at which they are discharged—is greater the higher the intensity and the longer the duration of the stimulating flash. Intensity and duration, indeed, both affect the response of the sense cell to the same extent quantitatively,

[4] H. K. Hartline, J. Cell. and Comp. Physiol. **5**, 229 (1934).

as may be seen in Fig. 2. The recorded responses which stand in a diagonal of this array (upper left to lower right) are very closely equal; for each of these responses the energy of the stimulating flash was the same. This property of the visual sense cell may be ascribed to the photochemical reaction which is the first step in the action of light on the receptor. Apparently this reaction is sufficiently simple that the reciprocity law of photochemistry applies to it, provided only short durations of exposure are considered.

The wave-length of the stimulating light also affects the discharge of impulses from a visual sense cell.[5] For a given energy content, green light produces stronger discharges than does light from either the red or the violet ends of the spectrum. The differences, however, are purely quantitative, and it is merely necessary to increase the incident energy of the less effective wave-lengths in order to produce responses from the sense cell which are practically identical (Fig. 3). The difference in effectiveness of light from different parts of the spectrum may be explained simply,[6] since it is known that the absorption of light by the photosensitive substance of the sense cell varies with wave-length. To produce a given response requires a certain specific amount of photochemical change, and this in turn requires that a constant amount of energy be absorbed; the incident energies of lights of different wave-lengths must therefore be adjusted in inverse ratio to the degree to which they are absorbed (neglecting corrections due to quantum size, and possible selective absorption of the layer of transparent chitin overlying the sense cell). Thus the "visibility curve" for the single visual sense cell (Fig. 4) may be interpreted as the absorption spectrum of the photosensitive substance responsible for its excitation.

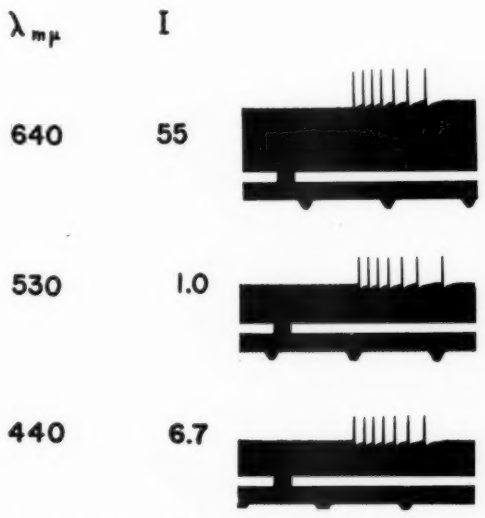

FIG. 3. Impulses in a single optic nerve fiber (*Limulus*) in response to lights of different wave-lengths, showing that responses can be made practically identical by suitable adjustment of the incident energies. Column headed λ mμ gives the value of the central wave-length of the spectral band (Wratten Monochromatic filters+35 mm 1 percent $CuCl_2$ solution). Column headed *I* gives relative intensities incident on the eye (thermopile determinations; value at λ = 530 mμ set equal to unity). Duration of stimulus flash 0.04 sec. (from Graham and Hartline, 1935).

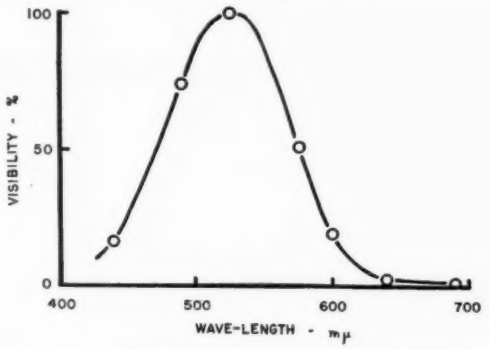

FIG. 4. Visibility curve for a single visual sense cell (*Limulus*). "Visibility" of each spectral band is the reciprocal of the relative intensity necessary to produce a specified burst of impulses (cf. Fig. 3). Value at λ = 530 mμ set equal to unity (data from Graham and Hartline, 1935).

It is evident that the single visual sense cell can only gauge the brightness of the stimulating light; it cannot distinguish color. Nor is the explanation of the differences in quality evoked by lights of different wave-lengths to be sought in the properties of an isolated receptor element and its nerve fiber. The arrival of a nerve impulse at the termination of a sensory fiber can only signal that something has happened elsewhere along the fiber, capable of stimulating it. As is well known, different kinds of stimuli are dis-

[5] C. H. Graham and H. K. Hartline, J. Gen. Physiol. **18**, 917 (1935).

[6] S. Hecht and R. E. Williams, J. Gen. Physiol. **5**, 1 (1922).

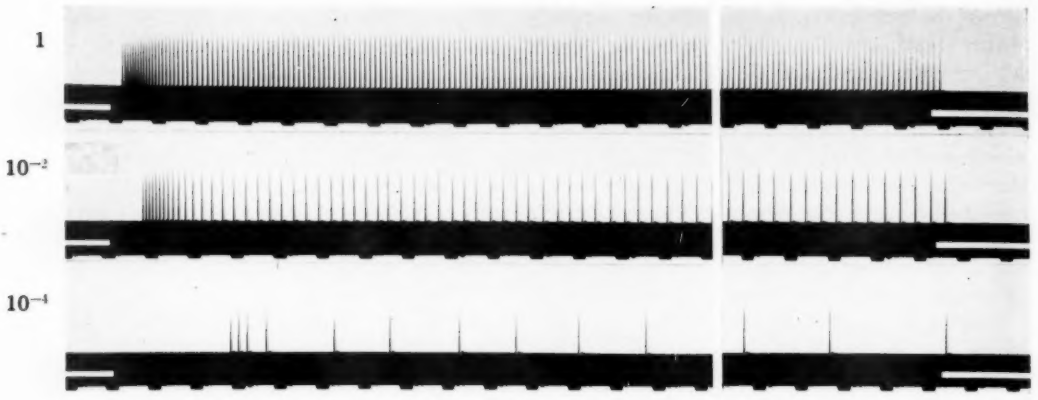

FIG. 5. Discharge of impulses in an optic nerve fiber (*Limulus*) in response to prolonged illumination of the eye, at three different intensities (relative values given at left). Eye partially light adapted. Signal of exposure to light blackens out white line above time marker. Time marked in $\frac{1}{5}$ second.

tinguished by virtue of the fact that they excite different groups of sensory nerve fibers, and to accomplish this the receptor elements in each sense organ must be sensitive to the particular physical agent which it is their function to detect, and relatively insensitive to all others. Only in this way can the presence of impulses in a specific group of nerve fibers serve as unambiguous signals of the action of a particular environmental agent. The visual receptor cells are specially provided with a photolabile substance which renders them sensitive to light. To distinguish the kind of light still further specialization is necessary: certain of the receptor elements must be relatively more sensitive than others to certain wave-lengths. Even in the primitive eye of the king-crab it has been possible to show that different sense cells do differ somewhat in the distribution of their sensitivity throughout the spectrum.[5] Although these differences are not great, it is permissible to consider them a direct experimental basis for the mechanism of color vision postulated by the Young-Helmholtz theory.

The photochemical change produced by light necessarily results in a depletion of the photosensitive substance of the sensory cell. Consequently, the sensitivity of the receptor falls during the continued action of the illumination. Fig. 5 shows that the discharge of impulses in response to steady illumination begins at a relatively high frequency, but that as the light continues to shine the frequency of the discharge declines. This "sensory adaptation" may be ascribed, at least in part, to the depletion of photosensitive material due to the action of the light. The discharge, however, does not subside completely, but reaches a steady level at which impulses continue to be discharged as long as the light shines. Evidently there are restorative processes in the sense cell which can maintain the supply of photosensitive material even in the face of active photolysis. A stationary state is reached when the rate of the restorative reaction equals that of the photolysis;[7] its level depends on the intensity of illumination, and in turn determines the level of frequency of the discharge of impulses in the nerve fiber.

The decrease in sensitivity of the visual receptor, resulting from exposure to light, may also be observed by turning the light off and then applying a short test flash. The burst of impulses in response to the flash is much diminished, compared with the response elicited by this same test flash before exposing the eye to light. As the eye is allowed to remain in the dark, following an exposure, test flashes of constant energy applied at intervals show a progressive recovery of the sensitivity of the receptor cell—the familiar process of dark adaptation (Fig. 6). This may be ascribed in part to the restorative process, now unopposed by photolysis, which brings about the

[7] S. Hecht, J. App. Phys. **9**, 156 (1937); Physiol. Rev. **17**, 239 (1937).

accumulation of photosensitive material until its original level of concentration has been regained.

These reactions of photolysis and regeneration of photosensitive materials are not purely hypothetical; direct chemical studies of photosensitive substances which can be extracted from the eyes of vertebrates furnish a sound basis for our understanding of the photochemical mechanism of the visual receptor.[8] Not only can the photosensitive substances and their photoproducts be identified chemically, in some cases, but the photochemical reactions and the recombination of the photoproducts may be observed *in vitro*. Thus the first step in the excitation of the visual sense cell is beginning to be understood. On the other hand, very little is known about the processes intermediate between the initial photochemical reaction and the final discharge of nerve impulses.[9] This aspect of the problem, however, is not confined to the visual sense cell; it is part of more fundamental questions concerning the excitation of nerve cells of any kind, and the mechanisms whereby they initiate trains of impulses in their fibers.[1,2,10] We will now leave the consideration of the receptor element and take up another aspect of the visual problem.

The activity of the visual sense cell and its nerve fiber is but the beginning of the visual process. Subsequent events in the chains of nerve cells constituting the visual pathways have been explored, to only a limited degree as yet, by the same methods used to study the activity of the receptor elements. For this purpose the eyes of vertebrates may profitably be investigated.[11,12] The optic nerve fibers in the vertebrate eye arise from the ganglion cells of the retina[13]—the third neurons in the chain, counting the receptor elements (rods and cones) as the first. Consequently their activity is considerably more complicated than the simple receptor responses which have been described in the first part of this paper.

[8] G. Wald (this symposium), J. Opt. Soc. Am., to be published.
[9] H. K. Hartline, Cold Spring Harbor Symposia **3**, 245 (1935).
[10] D. W. Bronk and F. Brink, Ann. Rev. Physiol. **1**, 385 (1939).
[11] E. D. Adrian and R. Matthews, J. Physiol. **63**, 378 (1927); **64**, 279 (1927); **65**, 273 (1928).
[12] R. Granit, Documenta Ophthalmologica **1**, 7 (1938).
[13] S. R. Detwiler (this symposium), J. Opt. Soc. Am. **30**, 42 (1940).

A slightly different procedure is necessary to record the discharge of impulses in single optic nerve fibers from the vertebrate eye.[14] The eye of a frog is removed and opened, and its cornea, lens and vitreous humor are removed, exposing the retina. The optic nerve fibers form a thin layer on the surface of the retina, and small bundles of them may be dissected from the retina near the point where they converge to form the optic nerve proper. Such a bundle, split until only a single nerve fiber remains active, may be placed on electrodes and its electrical activity recorded in the usual manner. The retina is then explored with a small spot of light to determine the region which must be illuminated in order to elicit a discharge of impulses in the fiber.

In a simple eye such as that of the king-crab, where the optic nerve fibers arise directly from

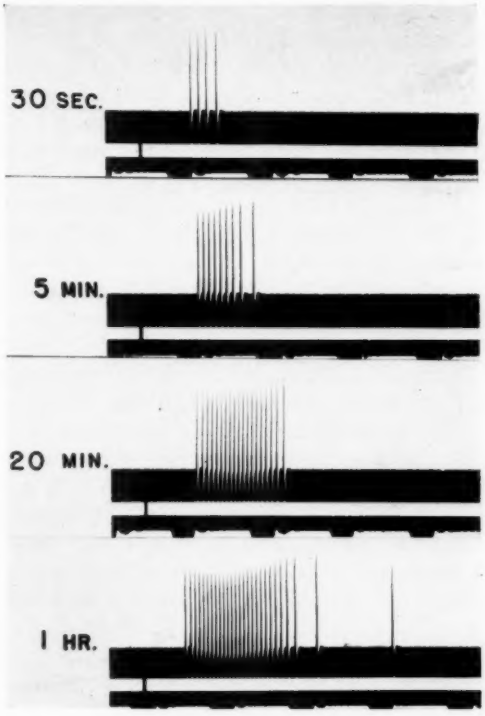

FIG. 6. Dark adaptation of a visual sense cell. Bursts of impulses in an optic nerve fiber (*Limulus*) in response to a test flash (0.01 sec., fixed intensity) thrown upon the eye at various times (given at left) following an adapting exposure. Signal of flash appears in white line above time marker. Time marked in $\frac{1}{2}$ sec.

[14] H. K. Hartline, Am. J. Physiol. **121**, 400 (1938).

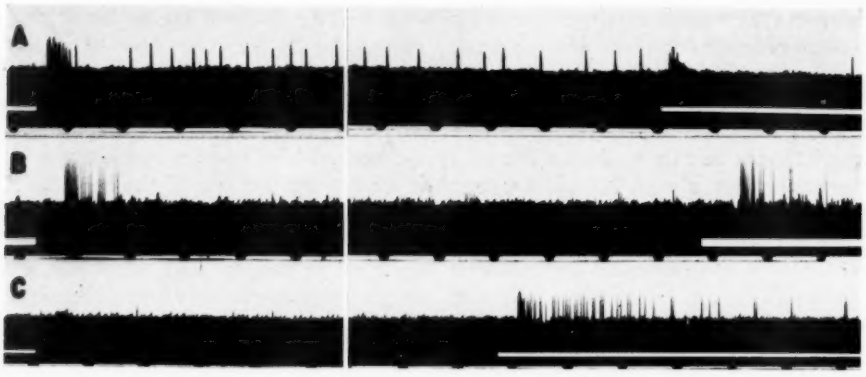

FIG. 7. Oscillograms showing the discharge of impulses in single optic nerve fibers of the vertebrate eye (frog), illustrating the three most common types of response to illumination of the retina. Individual deflections are *ca.* 50–100μv. High noise level on base-line due to large resistance of the very fine nerve strands across amplifier input. Signal of the exposure to light blackens out white line above time marker. Time marked in $\frac{1}{2}$ second. (From Hartline, 1938.)

the receptor cells, the responses in all the fibers are essentially similar. In the vertebrate eye, however, the discharges in different fibers differ widely. Fig. 7 shows oscillograms of the electrical activity in single optic nerve fibers from the eye of the frog; the three types of responses most commonly met with are given. In some of the fibers (Fig. 7, (A)) the discharge is similar to that from a simple receptor cell: impulses are discharged regularly as long as the light shines. Other fibers (Fig. 7, (B)) discharge impulses only briefly, when the light is turned on and again when it is turned off, with no activity whatever as long as it shines steadily. The "off" responses in these fibers are a striking departure from simple sense-organ activity. Even more surprising are the fibers whose only response occurs when the light is turned off (Fig. 7, (C)). These different kinds of responses are not due to different conditions of stimulation or adaptation of the retina; a given optic nerve fiber has its fixed pattern of response, and fibers with different types of response can usually be found in the same small bundle of fibers, coming from closely adjacent regions of the retina. While no certain explanation of this diversity of response can be given, it seems reasonable to ascribe it to the action of the complex nervous structures of the retina interposed between the receptor elements and the ganglion cells giving rise to the optic nerve fibers.

The same factors which have been shown to determine the responses of the visual sense cells in the eye of the king-crab likewise affect the discharge of impulses in the vertebrate optic nerve fibers. Thus the frequency of the discharge is greater the higher the intensity of the retinal illumination; likewise the sensitivity of the retina is diminished by light-adaptation and recovers as it is allowed to remain in darkness. In addition, certain new properties emerge. The fibers responding with short bursts of impulses at the onset and cessation of illumination also respond even to slight changes in intensity—the greater the change the stronger the response. These fibers are also extremely sensitive to movement of the retinal image, whether it be a spot of light or a small shadow on the uniformly illuminated retina (Fig. 8, upper record). The higher the intensity, and the more rapid and more extensive the movement, the greater the number of impulses discharged in response. The importance of this type of response to the animal is obvious.

The discharge of impulses in fibers which respond only to turning the light off usually subsides in a second or two; the initial frequency and the duration of this discharge are greater the higher the intensity and the longer the duration of the preceding exposure. Thus the "off" responses are strictly dependent on the previous illumination, although these ganglion cells dis-

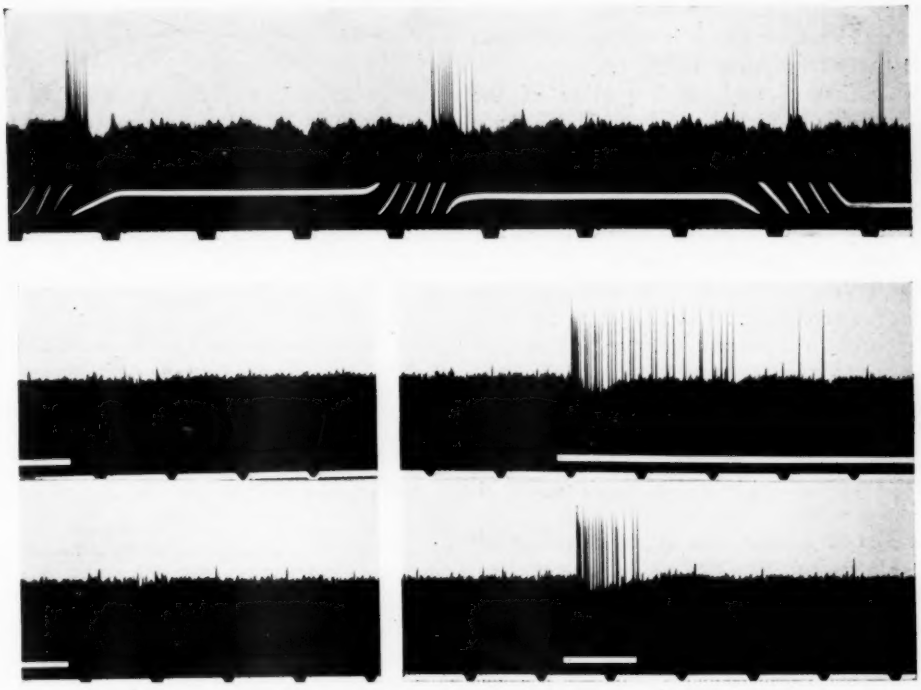

FIG. 8. Records of impulses discharged in single optic nerve fibers of the vertebrate eye (frog). Upper record: responses to movement of small spot of light on retina (diameter of spot 50μ). White lines above time marker signal the movement; they are shadows of spokes attached to the micrometer screw driving spot of light across the retina. Each spoke equivalent to 7μ on retina. Nerve fiber was one responding to "on" and "off" (as in Fig. 7(B)). Lower records: discharge of impulses in a fiber responding only to cessation of illumination (as in Fig. 7(C)), showing how the full response (upper record of this pair) can be abruptly cut short by re-illumination of the retina (lower record). Signal of retinal illumination blackens out white line above time marker. Time in $\frac{1}{5}$ second.

charge no impulses during the period when their excitation is being built up. Indeed, the discharge in these fibers can be abruptly suppressed at any time merely by re-illuminating the retina (Fig. 8, lower record). This is strongly reminiscent of the behavior of other parts of the nervous system, where stimulation which excites some nerve cells to discharge impulses can inhibit the activity of others.[12]

In the eye of the king-crab, responses in a given optic nerve fiber can only be elicited by illumination of one particular facet of the eye—that one containing the fiber's receptor cell. In the vertebrate retina a single optic nerve fiber, it is true, can only be excited by light falling upon a restricted region of the retina; this region, however, has appreciable extent.[14] It usually covers about one square millimeter of retinal area, comprising many hundreds of receptor elements. The anatomical basis for this fundamental property of the peripheral vertebrate retina is well known; a single retinal ganglion cell is connected with many rods or cones.[13, 15] The retinal region occupied by visual sense cells whose connections converge upon a given retinal ganglion cell is termed the receptive field of that ganglion cell. By exploring the retina with a small spot of light, while recording the activity in an optic nerve fiber, the receptive field of the fiber may be charted.[16] It has been found that the sensitivity of the retina, defined with respect to a particular fiber, is not uniformly distributed over that fiber's receptive field, but is maximal in the center and falls off

[15] R. J. Lythgoe, Proc. Phys. Soc. **50**, 321 (1938).
[16] H. K. Hartline (in preparation).

gradually with increasing distance from this center. Fig. 9 is a contour map of the distribution of sensitivity for a particular fiber.

Illumination of any small portion of the receptive field of a retinal ganglion cell, if intense enough, can elicit a discharge of impulses in its optic nerve fiber. It is not surprising to find that the more of these convergent pathways brought into activity, by increasing the area of the retina illuminated, the stronger is the response of the ganglion cell.[11, 16] Thus spatial summation takes place in the vertebrate retina, based on the convergence of retinal pathways upon the ganglion cells. Both convergence and the spatial summation which may result from it are of fundamental importance throughout the nervous system. In the present experiments they serve to illustrate how general principles of nervous action apply to the visual system.

Because many receptor elements are connected with each retinal ganglion cell, the acuity of vision in the peripheral retina is poor. A discharge of impulses in a particular optic nerve fiber signifies only that light has fallen on the retina somewhere within the rather extensive receptive field of that fiber. Moreover, the receptive fields of individual optic nerve fibers overlap considerably, so that a single small spot of light produces activity in many fibers. This may be observed experimentally in bundles which have not been split by dissection, so that many optic nerve fibers remain active.[16] Usually the activity in the various fibers can be distinguished (if there are not too many of them) by slight differences in their impulses, as observed with the aid of an oscilloscope. From such experiments it is possible to reconstruct the representation in the optic nerve of an illuminated point on the retina. A given element of retinal area lies within the central, most sensitive region of the receptive fields of certain optic nerve fibers; these fibers will be stimulated effectively by illumination of this element of area. For other fibers this point lies in the less sensitive marginal areas of their receptive fields, and these fibers will be activated less strongly by illumination of this particular element of retinal area. Illumination of a particular point on the retina therefore elicits a specific pattern of activity among the fibers of the optic nerve. The specific fibers involved, and

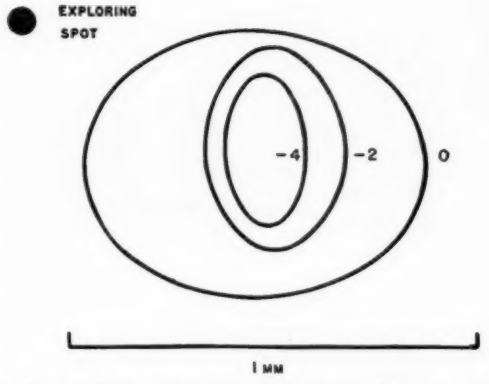

FIG. 9. Chart of the retinal region supplying a single optic nerve fiber (eye of a frog). Each curve encloses the retinal region within which the exploring spot of light (relative size shown at upper left) produced responses in the fiber, at an intensity of illumination whose logarithm is given on the respective curve. On each curve itself the indicated intensity was just threshold; the set of curves constitute a contour map of the distribution of sensitivity to light over the retina, referred to this particular fiber.

the relative strengths of the discharges of nerve impulses they transmit, are characteristic of this particular point. Corresponding to other points are different patterns of activity; even two closely adjacent points do not produce quite the same distribution of activity, although they may excite many fibers in common. This may be observed directly, by watching on the oscilloscope the altered pattern of electrical activity resulting as a small spot of light is tested at different positions on the retina. For two points on the retina to be resolved, they need not necessarily be separated so widely that they activate entirely separate groups of optic nerve fibers; it might suffice if two discrete maxima of activity are produced among the fibers involved. Nevertheless, one can hardly expect the resolution to be as effective as in the fovea, where each optic nerve fiber probably corresponds to only one receptor element.[13, 15]

The experiments reviewed in this paper illustrate the analysis of visual function by direct experimental studies of the activity of individual cellular units. They show how familiar phenomena of vision may be traced to properties of the receptor cells, based on their physical and chemical constitution. In most cases the interpretations which have been given are not new; the experiments merely replace inference and deduc-

tion by direct observation. As one proceeds from the receptor cells to the higher nerve cells of the visual pathway, new problems arise due to the interaction between the individual units; these experiments indicate how general principles of nervous action may be applied toward a solution of these difficult problems. They emphasize especially the necessity for considering patterns of activity in the nervous system. Individual cellular units never act independently; it is the integrated action of all the units of the visual system that gives rise to vision.

Pan-American Congress of Ophthalmology in Cleveland Next October

PLANS for a Pan-American Congress of Ophthalmology to be held at the Hotel Cleveland, Cleveland, Ohio, October 11–12, have been announced. The congress will be sponsored by the American Academy of Ophthalmology and Otolaryngology, an organization of more than 2500 specialists in diseases of the eye, ear, nose and throat, which will hold its annual convention immediately preceding the Pan-American gathering.

The U. S. Department of State has expressed its interest in the Congress and the governments of all the countries of the Western Hemisphere have been invited to send official delegates. It is felt that the meeting will do much toward bringing about an *entente cordiale* among scientific men of the two Americas, and it is expected that a permanent organization will be effected.

The committee that is developing the congress has the following members: Drs. Harry Gradle, Chicago; Conrad Berens, New York, and Moacyr E. Alvaro, Sao Paulo, Brazil. The executive secretary of the American Academy of Ophthalmology and Otolaryngology, which will be host to the Latin-American eye specialists, is Dr. William P. Wherry, 1500 Medical Arts Building, Omaha, Nebraska.

Under the direction of Dr. Berens, papers in Spanish or Portuguese will be made understandable to English speaking ophthalmologists by the use of lantern slides projecting a synopsis of each paragraph translated into English. The reverse process will be used with the English papers. Spanish and Portuguese stenographers will be present to record the discussions in the language of the authors.

The congress is open to any ophthalmologist who wishes to register. Nonmembers of the Academy of Ophthalmology and Otolaryngology may register regardless of attendance at the Academy meeting proper. Individual invitations have been sent to about 1800 members of the ophthalmologic profession in the Latin-American countries, as well as to the national societies of eye specialists and the universities. Individual invitations were not sent to ophthalmologists in the United States and Canada, but official invitations to them are being printed in the various journals of ophthalmology. A fee of $5 has been set for membership in the congress.

A New Two-Color Optical Pyrometer*

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(Received April 13, 1940)

THE monochromatic optical pyrometer fails if either the emissivity of the source or the transmission of the intervening space is unknown or variable.

The Wien law

$$E_{\lambda_1}=c_1\epsilon_{\lambda_1}\lambda_1^{-5}e^{-c_2/\lambda_1 T} \tag{1}$$

will provide only an "apparent" temperature if the emissivity ϵ_{λ_1} is unknown. If, however, it may be assumed that "grey" conditions exist so the ϵ_{λ_2} at some other wave-length, is the same as ϵ_{λ_1} then a second monochromatic optical pyrometer working at λ_2 may be used according to the equation.

$$E_{\lambda_2}=c_1\epsilon_{\lambda_1}\lambda_2^{-5}e^{-c_2/\lambda_2 T}. \tag{2}$$

Eliminating $\epsilon_{\lambda_1}(=\epsilon_{\lambda_2})$ gives

$$\frac{E_{\lambda_1}}{E_{\lambda_2}}=\left(\frac{\lambda_2}{\lambda_1}\right)^5\exp\left[\frac{c_2}{T}\left(\frac{1}{\lambda_2}-\frac{1}{\lambda_1}\right)\right]. \tag{3}$$

Temperatures have been measured in the laboratory by the use of two pyrometers, one operating in the red and the other in the green, but obviously both the temperature and the emissivity must remain quite constant throughout the period of the measurements.

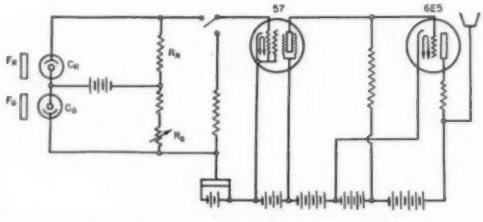

FIG. 1. Electrical circuit of the portable two-color photoelectric optical pyrometer.

* Presented at the American Institute of Physics Symposium on Temperature, Its Measurement and Control in Science and Industry, New York, New York, November 2–4, 1939.

Equation (3) may be put in the form

$$\log E_{\lambda_1}/E_{\lambda_2}=A+B/T.$$

This indicates that if the ratio of the intensities of two radiations of different wave-lengths is directly determined it will provide a direct measure of the temperature. This further suggests the use of photoelectric cells and some electric circuit which will respond directly to the ratio of their outputs. The quantity A will then contain an instrumental constant which is dependent on the response of the circuit to E_{λ_1} and E_{λ_2}. The quantity B is fixed by the wave-lengths used.

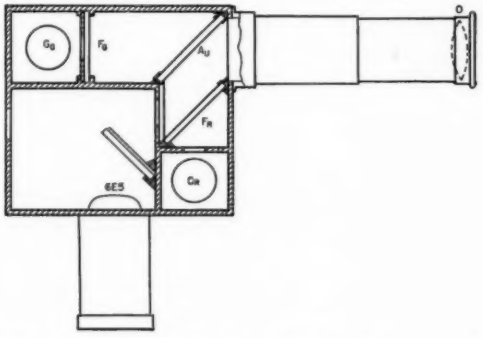

FIG. 2. Schematic drawing of the portable two-color photoelectric optical pyrometer head showing the optical system used in separating and filtering the incident radiation.

A circuit which directly indicates a quantity proportional to the ratio of the intensity of two radiations is shown in Fig. 1. When the Wheatstone network consisting of the two cells C_R and C_G and the two resistances R_R and R_G is balanced by manually adjusting one of the resistances, the ratio of the photoelectric currents is equal to the inverse ratio of the resistances. A 6E5 visual tuning tube is used as the null detector preceded by a 57-tube amplifier.

FIG. 3. The portable two-color photoelectric optical pyrometer in use measuring furnace temperature.

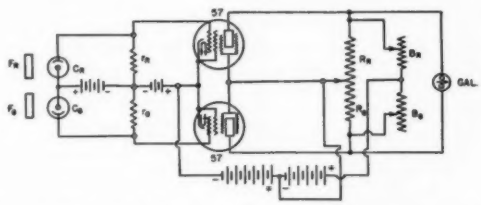

FIG. 4. Electrical circuit of the recording type two-color photoelectric optical pyrometer.

The pyrometer head is shown in Fig. 2. Light from the objective lens O strikes an inclined semi-transparent gold mirror Au. The transmitted green light is passed on through a green glass filter F_G on to a photo-cell C_G. The red reflected light passes through a red glass filter F_R on to the other cell C_R. Vacuum type Cs−O−Ag cells are used to provide maximum stability with high resistivity. The pyrometer is sighted through the back peep hole, on light reflected from the surfaces of the red filter. The null detector tube 6E5 contained in the handle is visible at the same time in the mirror above it.

Figure 3 is a photograph of the entire instrument showing the pyrometer head, and the box containing the variable resistance and batteries. Part of the power is supplied as alternating current by a cord to a power pack in the box.

A less portable, but automatically recording form of two-color pyrometer has also been constructed. The electrical circuit is shown schematically in Fig. 4. In this instrument amplifying tubes 57 for each photo-cell C_R and C_G are contained in the pyrometer head, permitting the

FIG. 5. The recording two-color photoelectric optical pyrometer being focused preliminary to the recording of furnace temperature.

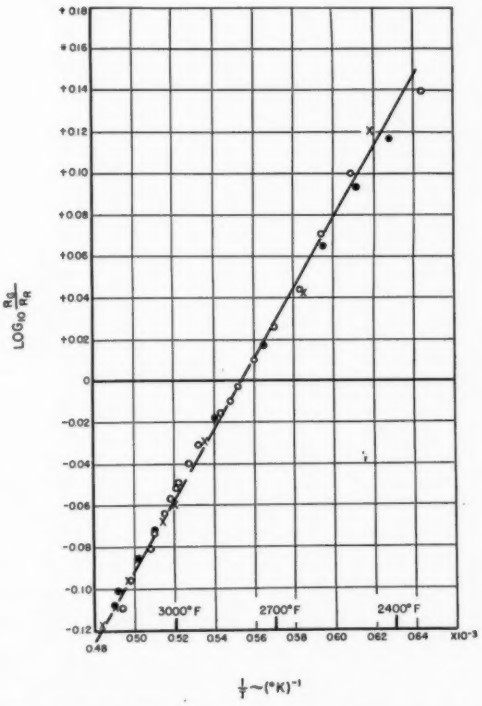

FIG. 6. A plot of the data obtained on three separate days for the calibration of the recording two-color photoelectric optical pyrometer. The actual source temperatures are indicated in °F.

use of a low resistance external circuit. The ratio determining resistance consisting of R_R and R_G is carried by the drum of a self-balancing recorder. Those portions of the plate currents which do not vary with the light intensity are balanced out by adjustable resistances B_R and B_G in the circuit commonly used for this purpose. Switches, not represented, permit the galvanometer of the recorder to be used in this adjustment.

The recording type of pyrometer is shown in Fig. 5. The optical system of this pyrometer is essentially the same as that of the portable type. The cabinet at the right contains a power pack and voltage stabilizer and all of the low resistance circuit except the slidewire and galvanometer, which are in the recorder.

A calibration curve of the recording pyrometer is shown in Fig. 6. This contains data secured on three separate occasions on graphite crucibles heated in an induction furnace, comparison temperatures being secured by a disappearing filament optical pyrometer. Note that the log of the ratio of the resistances varies linearly with the reciprocal of the absolute temperature. On changing the electrical characteristics of the circuit the curve is displaced parallel to itself, but, in agreement with theory the slope remains unchanged if there is no change in the mean effective wave-lengths. Thus, under good conditions, a check at a single temperature could provide a calibration of the entire scale of the instrument.

The two-color pyrometers are operative on sources having temperatures over 1000°C. Small high temperature sources can be measured, but the results are subject to possible error due to variation of the sensitivity of the photoelectric cells from one point to another on their surface, so that in general the source should be large enough to fill the field stop. Reliable measurements at the temperature of molten plain carbon steel can be secured even in the presence of a small amount of smoke. The fumes from high manganese steel transmit the red selectively and seriously disturb the recordings.

The portable pyrometer is electrically the more stable but is not quite as sensitive as the recording pyrometer. Instability in the electrical circuit of the recording pyrometer has not yet been entirely eliminated, so that adjustments must be made about every half-hour. An unexpected difficulty arises from the fact that an ordinary red glass filter varies in transmission as its temperature varies. This has not yet been corrected. At present the readings of the pyrometer are subject to errors of about 10°C.

Exact and Approximate Computation of Schmidt Cameras

I. The Classical Arrangement

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The Schmidt camera is particularly advantageous in certain astronomical and spectrographic studies. This paper gives an exact derivation for the equation of the correcting surface, together with some approximations rather more precise than those previously available. Performance of actual instruments made according to the old and new equations will differ significantly if the surfaces are figured with exceptional care.

FOR a restricted range of optical work, it is desirable to have a telescopic camera of low focal ratio and high resolving power over a comparatively broad angular field. In astronomy, these requirements hold wherever faint extended light sources must be used, as with gaseous nebulae and comets, and also when rapid survey photographs of large star fields are desired. In spectrography, such a camera is particularly indicated for short spectral ranges with low intensity sources, as in Raman and fluorescence studies.

Schmidt[1] pointed out that a spherical mirror with a stop at the center of curvature gives an image free of astigmatism, and designed a correcting plate to remove axial spherical aberration. This plate also corrects coma almost completely over a wide field; so that the system acts as a practically aplanatic telescope for its whole focal surface. The advantages and disadvantages of this construction for astronomical and spectrum photography have been discussed previously.[1-3]

The correcting plate required is practically plane-parallel, only slight figuring on one side being necessary. To enable the use of the smallest deviations and most accurate corrections, the plate should be formed as a weakly positive lens near the center, with gradual reduction of the power along a radius outward; so that finally the plate acts as a negative lens near the edge. For rays of a selected intermediate optical height h_s, the power is zero, and the axial spherical aberration is uncorrected. The equivalent focal length of the system is increased for rays of smaller optical height and reduced for those of greater. If the corrections are properly made, all rays will focus together with those of optical height h_s.

Apparently Schmidt himself never published the equation of the figured surface. Strömgren[2] gave an approximation to the third order, in the sense of Seidel's theory of aberrations. That is, he expressed the excavation required, x, as a function of the optical height of incident rays, h, in the form

$$x=\alpha h^2-\beta h^4+\cdots, \tag{1}$$

and gave instructions for evaluating α and β.

The problem, however, may be solved exactly, and, if desired, power series approximations may be derived from the exact solution. For telescopes of ordinary dimensions, the constants obtained differ only slightly from Strömgren's, but for telescopes of large aperture and relatively short focus, the more exact formulations may be desirable. Differences in notation between this paper and that of Strömgren are in part arbitrary and in part arise from the use here of the positive x direction for the incident light.

It is required to express the depth of excavation in terms of the optical height of an incident ray. The depth of excavation is also a function of the refractive index, n, of the plate, and the radius of curvature of the mirror. In the present development, this radius is suitably taken as the unit measure of distance: it is thus the scale factor of the system. A convenient parameter is the angle,

[1] B. Schmidt, Cent.-Zeitg. f. Optik u. Mechanik **52**, Heft 2 (1931), or Mitt. Hamburger Sternwarte Bergedorf **7**, Nr. 36 (1932).
[2] B. Strömgren, Vierteljahrss. d. Astronom. Ges. **70**, 65 (1935).
[3] O. Struve, Astrophys. J. **86**, 613 (1937).

ϕ, between the axis and the radius to the point of incidence of a ray on the mirror.

From a plane wave front outside the instrument the optical length must be the same for all rays reaching the focus. Three rays should be considered; namely, a paraxial ray, the selected undeviated ray, and a general ray parallel to the axis before incidence but at a moderate distance. The necessary values for finding their optical lengths may be determined from Fig. 1. All quantities referring to the paraxial ray have the subscript zero; all referring to the selected ray have the subscript s; while those referring to the general ray are without subscript.

The second principal point of the instrument may be located by dropping a perpendicular to the axis from the intersection of projections of a paraxial incident ray and the corresponding ray from the focus. To locate the intersection, one may solve simultaneously the equations of these rays. Recall that in the paraxial region arc = tan = sin. Referring to Fig. 1, we see that $\eta_0=\phi_0+(\delta_1+\delta_2)_0=\phi_0+\theta_0-2\phi_0=\theta_0-\phi_0$ is the equation for the projection of the incident ray, where η_0 is the ordinate. For the ray through the focus, $\eta=\xi\tan\theta$, $\eta_0=\xi_0\theta_0$, where ξ is the abcissa of a point on the ray. Thus the focal length $f=\xi_H=(\theta_0-\phi_0)/\theta_0=1-\phi_0/\theta_0$, ξ_H being the abcissa of the second principal point measured from F.

Let σ be the axial spherical aberration for the selected ray, and let L be the projection on the axis of a ray from the focus to the mirror. Then $L_0=\frac{1}{2}-\sigma$, and $\phi_0/L_0=\theta_0$, or $\phi_0/\theta_0=\frac{1}{2}-\sigma$. Therefore $f=\frac{1}{2}+\sigma$. The optical length of a paraxial ray is

$$\pi_0=nt_0+2-f, \tag{2}$$

measured from the first contact of the plate and wave-front to the focus. In terms of the chosen parameter ϕ, f may be evaluated as follows:

$\angle\,\infty P_sC=\phi_s$. alt. int. $\angle$'s =.
$\angle\,FP_sC=\phi_s$. $\angle$ incidence = $\angle$ reflection.

Therefore ΔCFP_s is isosceles, and $\overline{FP_s}=f$. Also

$\theta_s=2\phi_s$. ext. $\angle$ = sum of opp. int. $\angle$'s.

Therefore

$$f=L_s/\cos 2\phi_s. \tag{3}$$

Subtracting $1-\cos\phi$ (the sagitta) and $\frac{1}{2}+\sigma$ from the mirror radius, we find $L=\cos\phi-f$. Thus (3) becomes $f=(\cos\phi_s-f)/\cos 2\phi_s$, which readily reduces to

$$f=(2\cos\phi_s)^{-1}. \tag{4}$$

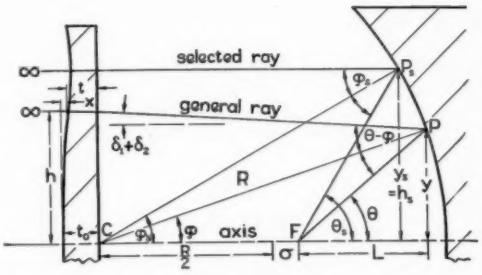

FIG. 1. Portion of meridian section through a Schmidt camera. Left shaded region is the transparent correcting plate, right shaded region is the first-surface spherical mirror. For focal ratios of $f:1$ to $f:3$, the curvatures of mirror and correcting surfaces will be very much less.

Also θ may be evaluated in terms of ϕ. The optical height of a ray at the mirror is $\sin\phi$. Then $\sin\phi/L=\tan\theta$; whence

$$\theta=\tan^{-1}[\sin\phi/(\cos\phi-f)].$$

Further, $\overline{FP}=L/\cos\theta$, or

$$\overline{FP}=(\cos\phi-f)/\cos\tan^{-1}[\sin\phi/(\cos\phi-f)].$$

Using the Pythagorean theorem, one may reduce this to

$$\overline{FP}=(1-2f\cos\phi+f^2)^{\frac{1}{2}}. \tag{5}$$

From Fig. 1 and Eq. (5), the general optical path is

$$\pi=x+nl/\cos\delta_1+\cos\phi/\cos(\delta_1+\delta_2)+(1-2f\cos\phi+f^2)^{\frac{1}{2}}; \tag{6}$$

where δ_1 and δ_2 are the deviations produced by the first and second faces of the correcting plate. Equating (2) and (6) and collecting,

$$x(n/\cos\delta_1-1)=\cos\phi/\cos(\delta_1+\delta_2)+(1-2f\cos\phi+f^2)^{\frac{1}{2}}+f-2-nt_0(1-1/\cos\delta_1), \tag{7}$$

where t_0 is the central thickness of the plate.

Equation (7) gives exactly the depth of figuring for the correcting plate. Since it is possible to compute δ_1 and δ_2, as detailed below, (7) could be used as it stands. This is not really convenient, however. Various less exact but simpler solutions are obtainable. For instance, differentiating (1),

$$dx=2\alpha h\,dh-4\beta h^3dh+\cdots. \tag{8}$$

At the incidence point of a selected ray, $dx_s/dh_s=0$; whence $\alpha=2\beta h_s^2$, or $\beta=\alpha/2h_s^2$. Substituting in (1),

$$x_s\backsimeq\alpha h_s^2-\alpha h_s^2/2\backsimeq\alpha h_s^2/2.$$

Then

$$x\backsimeq 2x_s h^2/h_s^2-x_s h^4/h_s^4. \tag{9}$$

From (7), x_s may be determined exactly; since for the selected ray

$$x_s=(\cos\phi_s+\sec\phi_s-2)/(n-1). \tag{10}$$

This is to be evaluated and substituted in (9). A trigonometric table may be used, but if none of sufficient precision is available, series expansions will serve, yielding

$$x_s=\phi_s^4/4(n-1)+\phi_s^6/12(n-1)+\cdots. \tag{11}$$

For most purposes, the ϕ^4 term alone will be enough, and insertion of terms higher than the second of (11) in (9) would be meaningless. If greater precision is required, more points should be computed from (7) or (12) below, and a power series fitted in the usual manner.

Another equation of intermediate precision, suitable for any telescope of size and proportions likely to be constructed, is

$$(n-1)x\backsimeq(1-2f\cos\phi+f^2)^{\frac{1}{2}}\times[1+1/(1-f\cos 2\phi/\cos\phi)]+f-2, \tag{12}$$

obtained from (7) by substitutions for δ_1 and δ_2, and cancellation of terms affecting only the eighth or further significant figures for an $f:2$ telescope.

Certain details of the derivation of (12) from (7) may be interesting. The reader will notice that $\cos\delta_1$ occurs in (7) only as a divisor of n. It is very close to unity, and equating it to one amounts approximately to correcting the ray for a wave-length very slightly different from that for which n is measured. In white light, image blurring from this source will be indistinguishable from that produced by the chromaticity of the plate. Only for a large spectrograph camera could it be worth while to consider $\delta_1\neq 0$. The term in $\delta_1+\delta_2$ is on a different footing. It is apparent from the construction of Fig. 1 that $\delta_1+\delta_2=\theta-2\phi$. Putting θ in terms of ϕ and collecting yields $\cos(\delta_1+\delta_2)=(\cos\phi-f\cos 2\phi)/(1-2f\cos\phi+f^2)^{\frac{1}{2}}$. Substitution of this in (7), together with $\cos\delta_1=1$, gives (12). Tracing a ray from the focus shows that $\cos\delta_1=[1-\sin^2(\theta-2\phi)/n^2]^{\frac{1}{2}}$; where

$$\theta=\tan^{-1}[\sin\phi/(\cos\phi-f)],$$

and, as noted above, this value may be substituted in (7) if it is ever important to have an exact solution.

The parameter ϕ enables the derivation of fairly compact expressions for x, but it must be remembered that $\sin\phi=y$, the optical height at the mirror, and therefore is not generally equal to the plate radius, h, for the intersection of the figured surface by the same ray. In fact, $\sin\phi$ should be corrected by $\delta_1+\delta_2$ in radian measure to get a sufficiently close approximation to h. An algebraic rather than trigonometric form of (12) results from the substitutions $y=\sin\phi$, $(1-y^2)^{\frac{1}{2}}=\cos\phi$. For coarser approximations, y and h may be used interchangeably.

Since n is a factor in the shape of the plate, the camera is corrected for one λ only. For other λ's, there will be a confusion disk at the best focus. This may be minimized by proper selection of ϕ_s. The radius of the plate for the selected ray should be somewhat less than the edge radius:

$$h_s/h_e=Y, \tag{13}$$

where Y is a proper fraction. Strömgren seems to prefer to choose $Y=0.866$; so as to have the least possible angular departure from flatness at any point of the plate. This means that the greatest chromatic error for any of the rays will be as small as possible.

Between the axis and selected ray, $|dx/dh|$ has a maximum at inflection, and drops to zero at h_s. Then it increases without limit as h increases. However, for $Y=0.866$, $|dx/dh|$ at the edge equals the value at inflection, as one may see by differentiating (9) and substituting this value of Y. Strömgren, though, states further that when the chromaticity blur becomes roughly equal in size to the blur produced by diffraction, 0.707 would be a better choice. This will be the case only for wave-lengths rather far from that selected, especially if glass of low dispersion is used for the correcting plate.

Another choice for Y would be that giving the smallest average deviation; thus concentrating the chromaticity blur near its center and getting the best possible resolving power. If the always-present effects of diffraction are neglected, it is

TABLE I.

EQUATION	x AT h_e	AT h_s	AT h_i
(7)	123.9	138.95	76.8
(12)	123.9	138.95	76.8
(17)	122.1	137.3	76.3
(18)	122.7	138.4	76.8

only necessary to minimize the integral of all deviations over the useful surface of the correcting plate. Part of the light through the plate will be intercepted by the film-holder, and in a spectrograph* the rectangular beam from the prism or grating will not fill the outer regions of the correcting plate. Thus the integral for an actual instrument should be minimized with consideration of such unused areas. These effects tend to cancel, and for a spectrograph, a sufficient approximation may be found by putting h_s for ϕ_s in (11), evaluating dx/dh, and assuming that the deviations of refracted light rays are proportional to the departure of the plate from flatness. Then

$$\int_0^{h_e} |h_s^2h^2 - h^4|\,dh = \text{minimum} \qquad (14)$$

is the desired condition. Here h_e is the edge radius. Constant factors outside the integral have been dropped: they do not affect the value of Y required for a minimum integral. The pales may be removed by dividing the range and taking the negative of the part beyond h_s:

$$\int_0^{h_s} (h_s^2h^2 - h^4)dh - \int_{h_s}^{h_e} (h_s^2h^2 - h^4)dh = \text{min.} \qquad (15)$$

Integrating, collecting, differentiating, and setting the derivative equal to zero, gives

$$Y = (\tfrac{1}{2})^{\frac{1}{2}} = 0.79. \qquad (16)$$

However, the exact value is not critical, and anything in the neighborhood of 0.8 is satisfactory.

* To get full advantage from a Schmidt camera in a spectrograph, one should use a Newtonian telescope as collimator. If a slit of small height is used, the only aberrations ahead of the camera will then be those caused by technical imperfections and by the unavoidable effects of diffraction.

Finally, in order to compute a telescope of the Schmidt type, one should select values for f, the ratio of Eq. (13), the mirror radius of curvature and edge radius, the plate edge radius, and should determine the thickness and refractive index of the plate. Then the equation for the aspherically figured surface may be found approximately from (11) or (10), with (9). A somewhat better approximation may be reached by the use of (12), or, if desired, the surface may be computed exactly from (7).

A numerical example is given in conclusion. Strömgren[2] gave a table of excavations for a telescope of 2 m radius of mirror curvature, 25 cm radius of correcting plate, $Y = 0.866$, and $n = 1.5$. With distances in mm, and using the notation of this paper, his equation is

$$x = 5.86 \cdot 10^{-3}h^2 - 6.25 \cdot 10^{-2}h^4. \qquad (17)$$

Use of the first term of Eq. (11) with (9) gives

$$x = 5.903 \cdot 10^{-3}h^2 - 6.302 \cdot 10^{-2}h^4. \qquad (18)$$

Table I shows a comparison of the values of x for sample values of h, using different equations. The tabulated numbers give the excavation in microns for values of h corresponding, respectively, to the edge of the plate, the selected (undeviated) ray, and the inflection.

The technical problem of figuring an aspherical surface to a quarter-wave-length is still the main obstruction to the use of the full resolving power of available photographic materials in a camera of large aperture and small focal ratio.

None of the differences between the values of x as obtained from (7) and (12) is greater than 0.004μ for the telescope here computed, and probably the differences are not appreciable for any telescope likely to be constructed. Thus the exact formula here derived is *per se* devoid of practical significance, but the approximations are better than the one previously available, and it is conceivable that a correcting plate can be figured accurately enough so that the improved calculations will be advantageous.

The Doppler Effect from Moving Mirrors

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(Received February 28, 1940)

PREVIOUS to the discovery of the Doppler effect in canal rays the only laboratory demonstration of the Doppler effect with light was that of Bélopolski and Galitzen[1] in which light was reflected back to the source from a rapidly moving mirror. In the experiment as performed, the light was reflected not once but several times, whereby the effect was made large enough for satisfactory measurement with an echelon spectroscope.

This Doppler effect, sometimes referred to as the "artificial Doppler effect" or "a sort of Doppler effect," differs from that observed with canal rays, or in the case of the stars, in that it cannot be expressed in terms of the relative motion of light source and observer, since there is no relative motion. It must be treated in terms of the motion of the radiation in the space between the light source, the mirrors, and the observer.

The formula for the frequency of the light returned to the source by a mirror moving away from it and oriented normally to the direction of motion, as obtained directly from wave theory, and given in several treatises on optics,[2] is

$$\nu' = \nu\left(\frac{c-v}{c+v}\right), \tag{1}$$

where ν is the frequency of the source, c the velocity of light, and v the velocity of the mirror. If the light is reflected back and forth a number of times, as by placing a stationary mirror at the source, the formula becomes

$$\nu' = \nu\left(\frac{c-v}{c+v}\right)^n, \tag{2}$$

where n is the number of incidences of light on the moving mirror.

This formula is developed for the case of source and observer being stationary in the ether. It is of interest to investigate the phenomena when the whole system is in uniform motion, as when the light source and observer are on a platform moving with the velocity V in the direction normal to the moving mirror. The formula for this case is simply obtained by double application of the formula (1). We note that a mirror placed at the moving light source would reflect the radiation incident on it with a frequency changed in the ratio $(c+V/c-V)$. This frequency is obviously that at which the radiation would strike the mirror. Applying this factor to the radiation returning from the moving mirror leads to the formula

$$\nu' = \nu\left(\frac{c+V}{c-V}\right)^n \left(\frac{c-(v+V)}{c+(v+V)}\right)^n, \tag{3}$$

where $(v+V)$ is the absolute velocity of the moving mirror.

An interesting question, which it is the purpose of this note to discuss, is whether this experiment would be fitted, as casual inspection of formula (3) suggests, to detect absolute motion through the ether. Or, looking at the question from another angle, what factors are available which would make this experiment, like all other optical experiments, yield a "null" result? It is not immediately obvious how the Fitzgerald contraction, and the Larmor-Lorentz change of clock rate, which are invoked for the Michelson-Morley experiment, can be operative here. The Fitzgerald contraction is not directly applicable because no lengths appear in the formula. The change of frequency of the light source in motion will cause no change in the observed effect since this frequency is itself our reference standard.

Inspection of formula (3) shows that there is only one factor which is subject to experimental manipulation, namely v, the velocity of the moving mirror. This velocity must be set *by measurement;* and in variations in its absolute

[1] Bélopolski and Galitzen, Acad. Sci. St. Petersburg Bull. 8, 213 (1907).
[2] Alfred O'Rahilly, *Electromagnetics* (Longmans, Green and Co., 1938), p. 339.

value when measured on platforms moving at different velocities must be found the desired modification of the formula. Calling this velocity v' when measured on the moving platform, and retaining v for the value on a stationary platform we seek the value of v' which shall make

$$\left[\frac{c+V}{c-V}\right]\left[\frac{c-v'-V}{c+v'+V}\right]=\frac{c-v}{c+v}. \tag{4}$$

Solving this relation we find

$$v'=\frac{v\left[1-\frac{V^2}{c^2}\right]}{1+\frac{Vv}{c^2}}. \tag{5}$$

We next investigate by what process of measurement we would be led to move the mirror at the velocity v on a stationary platform, and at the velocity

$$\frac{v\left[1-\frac{V^2}{c^2}\right]}{1+\frac{Vv}{c^2}}$$

on a platform moving with the velocity V. In order to do this, we consider the elementary method of velocity measurement consisting in counting divisions passing by a clock. The only way this process can lead to different results under different conditions, such as different velocities of the system, is for the length of the divisions, or the interval between clock ticks, or both, to vary. Let the divisions be on the mounting of the mirror, and let the clock be fixed at a point on the platform. Now with the platform stationary the velocity v will be read as

$$\frac{v}{L(v)}, \tag{6}$$

where $L(v)$ is some function of v representing the change in length of the divisions on the mirror mounting caused by its motion. With the platform moving we have for the corresponding measurement of velocity

$$\frac{v\left[1-\frac{V^2}{c^2}\right]}{1+\frac{Vv}{c^2}}\Bigg/F(V)\cdot L\left[\frac{v+V}{1+\frac{vV}{c^2}}\right], \tag{7}$$

where $F(V)$ is the factor by which the frequency of the clock on the moving platform is altered, and

$$L\left[\frac{v+V}{1+\frac{vV}{c^2}}\right]$$

is the same length altering factor as before, noting that the absolute velocity of the mirror is

$$v'+V=\frac{v\left[1-\frac{V^2}{c^2}\right]}{1+\frac{Vv}{c^2}}+V=\frac{v+V}{1+\frac{vV}{c^2}}. \tag{8}$$

We then put down as the result of setting the mirror to move on the moving platform at the same *measured* velocity as on the stationary platform

$$\frac{v}{L(v)}=\frac{v\left[1-\frac{V^2}{c^2}\right]}{\left[1+\frac{vV}{c^2}\right]\cdot F(V)\cdot L\left[\frac{v+V}{1+\frac{vV}{c^2}}\right]}. \tag{9}$$

Making use of the identity

$$1+\frac{vV}{c^2}=\frac{\left[1-\frac{v^2}{c^2}\right]^{\frac{1}{2}}\left[1-\frac{V^2}{c^2}\right]^{\frac{1}{2}}}{\left[1-\frac{(v+V)^2}{c^2\left[1+\frac{vV}{c^2}\right]^2}\right]^{\frac{1}{2}}} \tag{10}$$

(9) becomes

$$\frac{\left[1-\frac{v^2}{c^2}\right]^{\frac{1}{2}}}{L(v)}=\frac{\left[1-\frac{V^2}{c^2}\right]^{\frac{1}{2}}}{F(V)}\cdot\frac{\left[1-\frac{(v+V)^2}{c^2\left[1+\frac{vV}{c^2}\right]^2}\right]^{\frac{1}{2}}}{L\left[\frac{v+V}{1+\frac{Vv}{c^2}}\right]}, \quad (11)$$

from which

$$L(v)=\left[1-\frac{v^2}{c^2}\right]^{\frac{1}{2}},$$

$$L\left[\frac{v+V}{1+\frac{vV}{c^2}}\right]=\left[1-\frac{(v+V)^2}{c^2\left[1+\frac{Vv}{c^2}\right]^2}\right]^{\frac{1}{2}}, \quad (12)$$

$$F(V)=\left[1-\frac{V^2}{c^2}\right]^{\frac{1}{2}}.$$

These relations state that (for the experiment to give a "null" result), lengths and clock frequencies must be contracted in the ratio

$$\left[1-\left[\frac{\text{velocity}}{\text{velocity of light}}\right]^2\right]^{\frac{1}{2}}.$$

Since these are the alterations of length and clock rate to which is ascribed the result of the Michelson-Morley experiment, it follows that the Doppler effect with moving mirrors, if the experiment could be performed with adequate sensitivity, would likewise give a null result insofar as detecting absolute motion is concerned. The manner in which the contractions enter is however quite different. From these contractions it is possible to derive the Lorentz transformations,[3] and this elementary derivation is an example of Bateman's remark[4] that these transformations are derivable from study of the reflection of light from a moving mirror.

[3] H. E. Ives, J. Opt. Soc. Am. **27**, 263 (1937).
[4] H. Bateman, Bull. Nat. Research Council, Dec., 1922, p. 110.

Eighth Summer Conference on Applied Spectroscopy at the Massachusetts Institute of Technology

A PROGRAM of some thirty papers on the applications of spectroscopy to problems of biology, chemistry, geology, metallurgy, medicine, physics, and various industries, has been arranged for the eighth summer conference on spectroscopy and its applications, to be held in the George Eastman Laboratories of the Massachusetts Institute of Technology on July 15, 16 and 17, 1940.

As in previous years, morning and afternoon sessions will be held on all three days. The earlier sessions will be devoted to discussion of recent advances in spectrographic analysis of materials, both by emission and absorption methods, while later sessions will deal with specific applications of these techniques to the various scientific and industrial fields. The type of material to be discussed is represented in the proceedings of the fifth, sixth, and seventh conferences, published by John Wiley & Sons (New York).

Copies of the detailed program of the conference will be sent on request to anyone interested. Since the attendance is limited to two hundred, and as there are usually more than this number of applications, persons expecting to attend from a distance are urged to write in advance for reservations. No fees of any kind are charged in connection with the conference.

The usual summer courses on practical and applied spectroscopy, and a new course on line spectra, will be offered at the Institute between June 10 and July 20. Requests for special bulletins describing courses and conference, for reservations at the conference, or for the conference program, should be addressed to Professor George R. Harrison, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Research Note

A Subjective Phenomenon of Vision in Polarized Light

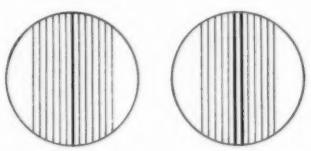
DURING the course of research in the field of atmospheric polarization the author discovered a phenomenon which seems to have escaped the attention of investigators. In any event, no mention could be found in the literature.

The author as geophysicist cannot attempt to explain a phenomenon so far outside of his own field. However, a description may furnish the expert additional knowledge of the structure of the human eye.

The phenomenon considered appears at and around the point of fixation, if one looks through Savart's double plate[1] into a field of bright, partially or totally polarized light (e.g., the blue sky).

The construction of Savart's double plate is based on the principle of chromatic polarization and consists of two quartz plates of equal thickness which are cut from a crystal at an angle of 45° to the optical axis. Both plates are cemented together with Canada balsam, the chief planes at right angle to each other. With an analyzer (e.g., Polaroid, Nicol's prism, etc.) between the eye and Savart's double plate, colored parallel interference bands are visible in polarized light. In Fig. 1 these bands are schematically shown in the two possible arrangements depending upon the position of the plane of polarization. Fig. 1(a) shows a brownish black band in the middle of the field, with adjacent white and colored bands on both sides. In Fig. 1(b) the complementary picture is demonstrated. These bands are objective and can be photographed.

The author found that the interference bands with a subjective modification are visible to the eye *without* analyzer. The phenomenon which appears in two patterns, analogous to those in Fig. 1, is shown in Fig. 2.



(a) (b)

FIG. 1.

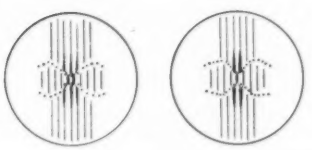


FIG. 2.

The thickness of the lines indicates the relative clearness of the various bands. The section in the center outlined by dotted lines represents the subjective modification of the bands and moves with the direction of fixation. The bands which are black, if seen through an analyzer, appear yellowish without analyzer. The adjacent bands are of faint colors. In the section between the dotted lines the interference bands appear in colors complementary to those above and below. The cell-shaped center part is at the same spot where the well-known phenomenon of Haidinger's brushes[2] appear to the eye. The subjective complementary section, however, is three to four times as large as Haidinger's brushes. The angular length of the whole phenomenon (parallel to the bands) amounts to 20–25°, the width to about 10°.

If Savart's double plate is slowly turned about an axis parallel to the bands while the eye holds its point of fixation, the bands (inside and outside the complementary section) which are produced by the quartz plates, move past the field of vision, whereas the outline of the subjective complementary section remains fixed.

The phenomenon described becomes very distinct if a dark blue glass filter is put in front of the quartz plates. Then all bands are dark with bright intervals. Seen through a light red filter the phenomenon is extremely faint, whereas in dark red light the author fails to see it at all.

Several persons were tested and all of them could see the phenomenon readily, especially in blue polarized light.

Although it is known that the eye has, to a certain extent, a polarizing effect upon the penetrating light, the phenomenon described above seems to suggest that this effect is a double one. The light penetrating into that part of the retina which produces the perception of the "complementary section" (see Fig. 2 between dotted lines) must (on its path through the eye) have been polarized in a different plane than the light that is perceived by the remaining part of the retina.

H. H. NEUBERGER

Geophysical Laboratory,
School of Mineral Industries,
The Pennsylvania State College,
State College, Pennsylvania,
February 25, 1940.

[1] Savart, Pogg. Ann. **49**, 292 (1840).
[2] *Helmholtz's Treatise on Physiological Optics*. Translated from third German edition (1924) Vol. II, p. 304–308.

Annual Report of the Secretary of the Optical Society of America for the Calendar Year 1939

Membership Record

January 1, 1939 to January 1, 1940

	Honorary	Regular Annual Payment	Regular Life Payment	Associate Individual Annual Payment	Associate Corporation	Total
Membership as of record in the books of the Secretary and Treasurer 1–1–1939	2	415	6	215	9	647
Gains during 1939						
By election as of 1–1–39	0	0	0	28	0	28
Losses during 1939						
By death	0	7–	0	1–	0	8–
By resignation as of 1–1–39	0	7–	0	6–	0	13–
Membership as of record 12–31–1939	2	401	6	236	9	654
Gains between 12–31–39 and 1–1–40						
By election during 1939 as of 1–1–40	0	0	0	10	1	11
By transfer 10–12–39 as of 1–1–40	0	26	0	0	0	26
Losses between 12–31–39 and 1–1–40						
By transfer 10–12–39 as of 1–1–40	0	0	0	26–	0	26–
By resignation during 1939 as of 12–31–39	0	4–	0	0	0	4–
By separation for nonpayment of dues	0	4–	0	6–	0	10–
Membership as of record 1–1–1940.	2	419	6	214	10	651

Elected during 1939 as of January 1, 1939

Frederick A. Babcock (1172 A)
Christopher E. Barthel, Jr. (1182 A)
Eugene W. Beggs (1164 R)
George A. Brueske (1156 A)
Willoughby M. Cady (1191 A)
Lawrence J. Davenport (1180 A)
Alexis A. B. Dember (1160 R)
Hans Dessauer (1179 A)
Lee Devol (1161 A)
M. Adelaide Easley (1170 A)
Josef B. Engl (1175 A)
Abraham P. Friesen (1158 A)
David Goldstein (1177 A)
Ernest H. Greppin (1169 R)
James H. Herron (1178 A)
Donald H. Jacobs (1176 A)
Benjamin J. King (1157 A)
Andrew P. Kruper (1181 A)
Harold Osterberg (1183 R)
John Pike (1168 A)
George Rattray (1166 A)
Shirleigh Silverman (1171 R)
Gereld Leon Tawney (1174 A)
Walter Wallin (1159 A)
Woldemar A. Weyl (1167 A)
Charles M. Wilson (1165 R)
Walter Wrigley (1163 A)
H. Gordon Young (1162 A)

Elected during 1939 as of January 1, 1940

Mildred Allen (1173 A)
Norman F. Barnes (1186 A)
Frederick W. Brock (1194 A)
Charles H. Evans (1187 A)
Glenn Ansel Fry (1184 R)
Alan M. Glover (1192 A)
Paul L. Hoover (1193 A)
Paul R. Irish (1185 A)
Edward L. McCarthy (1189 A)
John Spence (1188 A)
W. & L. E. Gurley (1190 AC)

Elected to Regular Membership by Action of the Board of Directors, October 12, 1939, effective as of January 1, 1940

Eugene W. Beggs (1164 R)
Janet H. Clark (337 R)
Robert C. Colwell (525 R)
Alan A. Cook (957 R)
Alexis A. B. Dember (1160 R)
Ralph K. Day (1139 R)
Ralph M. Evans (563 R)
Glenn A. Fry (1184 R)
Carl W. Gartlein (1154 R)
Hans Goldmann (1147 R)
Walter C. Granville (944 R)
Ernest H. Greppin (1169 R)
V. G. W. Harrison (1149 R)
H. Orlo Hoadley (1007 R)
Andrew Hustrulid (1024 R)
Oran E. Miller (1017 R)
John F. Morrow, Jr. (1034 R)
Bradford Noyes, Jr. (459 R)
Harold Osterberg (1183 R)
F. W. Reynolds (465 R)
Shirleigh Silverman (1171 R)
Luville T. Steadman (958 R)
Arthur F. Turner (1106 R)
Jack H. Waggoner (1090 R)
Charles M. Wilson (1165 R)
Harvey A. Zinszer (1141 R)

Deaths during 1939

Stuart Campbell (984 R) September 24, 1939
Arthur F. Dittmer (623 R) September 29, 1939
Edward E. Free (1065 R) November 24, 1939
H. D. Judd (68 R) January 1, 1939
Carl F. Lomb (979 A) January 26, 1939
Harold Mestre (624 R) September 9, 1939
J. B. Nathanson (403 R) November 25, 1939
F. K. Richtmyer (24 R) November 7, 1939

Resignations during 1939 as of January 1, 1939

Carl E. Bahn (942 R)
Bergen Davis (411 R)
Merril Distad (1048 A)
A. L. Fitch (808 A)
Edmund A. Georgi (1016 A)
Ernest A. Hutchinson (616 A)
Frederick L. Knowles (995 A)
Ernest O. Lawrence (570 R)
Gjon Mili (952 R)
Joseph Razek (704 R)
Horace C. Richards (618 R)
Bourdon F. Scribner (1067 A)
Dayton Ulrey (867 R)

Resignations during 1939 as of December 31, 1939

Wm. E. Curtis (833 R)
Ernst A. Hauser (1051 R)
R. M. Holmes (965 R)
Overton Luhr (921 R)

L. B. TUCKERMAN, *Secretary*

Annual Report of the Treasurer of the Optical Society of America for the Fiscal Year 1939

CASH TRANSACTIONS JANUARY 1, 1939 TO DECEMBER 31, 1939

Receipts

Dues	$4,307.58	
Dues in advance	1,796.74	
Interest on bonds	846.25	
Interest on bank balance	80.60	
Interest on Ives Medal Fund bonds	15.00	
Interest on A. Lomb Memorial Fund bonds	65.00	
Bank interest on Ives Medal Fund	1.87	
Bank interest on A. Lomb Memorial Fund	2.87	
Bank interest on Local Committee Fund	1.71	
Unbudgeted income	46.35	
		$7,163.97

Disbursements

Secretary's expense	$ 857.15	
Secretary's travel expense	31.20	
Treasurer's expense	355.49	
President's expense	18.25	
Journal publication expense	3,291.47	
Journal editorial expense	1,000.00	
Membership Committee expense	—	
Contingencies	9.69	
Ives Medal Fund expense	18.14	
Adolph Lomb Memorial Fund expense	—	
Local Committee expense	12.00	
Program Committee expense	83.19	
Specially appropriated expenditures		
Contribution to U.S. Committee I.C.I.	100.00	
Dues in Inter-Society Color Council	25.00	
		$5,801.58
Excess of receipts over disbursements		$1,362.39
Cash in bank, January 1, 1939	$5,166.54	
Balance interest Ives Medal Fund, January 1, 1939	97.19	
Balance interest A. Lomb Memorial Fund, January 1, 1939	94.34	
Local Committee Fund, January 1, 1939	88.42	$5,446.49
Cash Balance—December 31, 1939		$6,808.88

Frederic Ives Medal Fund

Income

Principal	$ 500.00	
Cash interest balance, January 1, 1939	97.19	
Bond interest accrued during 1939	15.00	
Bank interest on cash balance	1.87	
		$ 614.06
Disbursements		
Medal for A. H. Pfund	18.14	$ 18.14
Balance—December 31, 1939		$ 595.92

Note: The principal sum of $500.00 is invested in U. S. Treasury Certificates. They are included in the bonds reported in the accompanying Investment Statement.

Adolph Lomb Memorial Fund

Income

Invested principal (including purchase tax)	$1,919.06	
Uninvested principal, bond and bank interest, January 1, 1939	94.34	
Bond interest, December 31, 1939	65.00	
Bank interest, December 31, 1939	2.87	
		$2,081.27
Disbursements		
Cost of bonds (purchased in 1936)	$1,919.06	$1,919.06
Balance interest, uninvested capital in bank, December 31, 1939		$ 162.21

Note: The invested principal resides in Dominion of Canada 3¼% bonds bought during 1936. They are included in the bonds reported in the accompanying Investment Statement.

Local Committee Fund

Income

Cash balance, January 1, 1939	$ 88.42	
Bank interest, December 31, 1939	1.71	
		$ 90.13
Disbursements		
Expense for Fall meeting at Lake Placid Club	12.00	$ 12.00
Balance—December 31, 1939		$ 78.13

Securities Held by Security Trust Company of Rochester as Agent for the Optical Society of America, Inc.

	Cost	Market Value Jan. 22, 1940	Dividends During 1939	Rate of Return Against Cost
Bonds				
$7000. Atchison, Topeka & Santa Fe—4%	$ 6,916.25	$ 7,385.00	$280.00	4.05%
$2000. Dominion of Canada—3¼%	1,918.70	1,815.00	65.00	3.39%
$5600. U. S. Treasury Certificates—3¼%	5,625.67	6,120.80	182.00	3.23%
$8000. U. S. Treasury Certificates—3%	8,261.30	8,816.00	240.00	2.91%
Total Bonds	$22,721.92	$24,136.80	$767.00	3.39%
Stocks				
10 shares Eastman Kodak Common	$ 1,731.40	$ 1,615.00	$ 60.00	3.47%
40 shares General Electric Common	1,871.35	1,535.00	38.00	2.03%
35 shares Kennecott Copper Common	1,729.53	1,246.87	61.25	3.54%
Total Stocks	$ 5,332.28	$ 4,396.87	$159.25	2.99%
Totals and Average Return against Cost	$28,054.20	$28,533.67	$926.25	3.30%

Report of the Editor of Publications

Statement of Operations of the Journal of the Optical Society of America for the Year Ending December 31, 1939

(Compiled from data obtained from the American Institute of Physics and the Treasurer of the Society.)

A. In Account with American Institute of Physics Incorporated

Income			
Subscriptions		$4,659.58	
Net income from published articles (Schedule 1)		993.20	
Net income from single copies (Schedule 1)		100.73	$5,753.51
Expenses			
Printing and mailing		$6,262.20	
Editorial expenses (A. I. P. office)			
Salaries	$542.23		
Office expenses	160.19	702.42	
Business management expenses			
Salaries	$609.84		
Office expenses	149.34	759.18	
Miscellaneous		60.78	
Total expenses			$7,784.58
Excess of expense over income			$2,031.07
Service charge of American Institute of Physics (15%)			1,321.64
Contribution to A. I. P. in addition to service charge (5%)			440.55
Net cost of editorial mechanics, printing and distributing journal			$4,964.94

B. Expenses in editorial office (Ithaca)

Salaries	$1,000.00		
Miscellaneous	72.34		
Total in Ithaca office			$1,072.34
Total net cost of journal for 1939			$6,037.28

Number of pages published	1939	1938	1937	1936
Text and index	550	508	437	460
Covers and front matter	72	56	72	82
Total	622	564	509	542

Cumulative Index of the Journal of the Optical Society of America

Income		
Sales of Cumulative Index		$ 23.80
Expense		
Handling and mailing	$ 15.84	
20% Service charge	3.17	19.01
Net Income		$ 4.79

SCHEDULE 1

Net Income from Published Articles

Income		
"Per Page" publication charges	$1,422.00	
Sale of reprints	591.61	$2,013.61
Less: Uncollectible accounts	$ 160.02	1,853.59
Expense (in A. I. P. office)		
Manufacture and mailing of reprints	$ 738.62	
Business management salaries	97.44	
Business management office expense	24.33	$ 860.39
Net Income from published articles		$ 993.20

Net Income from Sale of Single Copies

Income—Sale of Single Copies		$ 266.75
Expense (in A. I. P. office)		
Business management salaries	$ 131.91	
Business management office	34.11	166.02
Net Income from sale of single copies		$ 100.73

Proceedings of the New York Meeting of the Optical Society of America

JOINT MEETING WITH THE AMERICAN PHYSICAL SOCIETY AND THE INTER-SOCIETY COLOR COUNCIL, NEW YORK, NEW YORK, FEBRUARY 21–24, 1940

THE joint meeting of the Optical Society of America, the American Physical Society, and the Inter-Society Color Council was held in New York City, February 21–24, 1940.

JOINT SYMPOSIUM ON OPTICAL METHODS FOR THE STUDY OF MOLECULAR STRUCTURE

A principal feature of the meeting was the symposium held before a joint session of the three organizations on Friday morning, February 23, devoted to invited papers on Optical Methods for the Study of Molecular Structure. The following papers were presented:

1. **The X-Ray Diffraction Method.**—B. E. WARREN, *Massachusetts Institute of Technology.*
2. **The Electronic Diffraction Method.**—LOUIS R. MAXWELL, *Department of Agricultural Chemistry and Engineering of the U. S. Department of Agriculture.*
3. **The Band Structure Method.**—R. BOWLING BARNES, *The American Cyanamid Company.*
4. **The Raman Spectra Method.**—GEORGE M. MURPHY, *Yale University.*

Following the symposium, much highly favorable comment was heard with regard to the individual papers and to the symposium as a whole.

Dr. Warren spoke on the x-ray diffraction method for studying molecular structures. He pointed out that the information secured by this method is purely geometrical relating to interatomic distances, relative positions of atoms, and, in favorable instances, the complete geometrical configurations of molecules.

Though molecular structure determinations can be made by x-ray diffraction experiments on a gas, the work is better done by electron diffraction. Likewise interatomic distances can be determined from the x-ray study of a liquid but there is difficulty in distinguishing intramolecular from intermolecular distances, hence the method is not very practical for such work. The great contributions of x-ray diffraction have come from the study of molecular crystals. A complete structure determination gives the coordinates of every atom in the structure and therefore the complete geometrical configuration of the molecule. Recent advances in Fourier analysis have made possible the working out of complex molecules which formerly were considered to be hopeless. X-ray photograms were shown to illustrate the various points brought forth. One slide was exhibited which showed the electron distribution in a phthalocyanine molecule as obtained from x-ray analyses.

Dr. Maxwell described the electron diffraction method, as applied to the study of free molecules, which has proved valuable to chemists in studies of the nature of the chemical bond and to physicists in analyses of spectroscopic data as well as in work on electric moments and other phenomena. In this method, an electron beam is scattered in traversing a concentrated beam of gas molecules. A theoretical discussion of the method was given which involved the theory of Debye and Ehrenfest for the analogous x-ray method. Slides were presented showing the apparatus used in Dr. Maxwell's laboratory, together with a summary of results for diatomic molecules and relationships to band spectra data. With electron diffraction photographs for illustration, phosphorus oxide structures were presented in greater detail, and recent results on the structure of NO_2, including work on molecules containing nitrite groups such as tetranitromethane, were also described.

The paper closed with an interesting preview of future problems in this field.

Dr. Barnes, in discussing the band spectra method, limited himself to an empirical approach. He called attention to the utility of the method in solving important practical problems which the chemist faces daily.

Discussion of the visible region was limited to absorption spectra of colored substances and to those that may be colored by titration. For the analysis of such spectra, attention was called

to the great importance of the spectrophotometer developed by Hardy which gives the percentage transmission of light to 0.1 percent in the visible region and with which a determination can be made in three minutes. The Beer absorption law makes possible both qualitative and quantitative chemical analyses from such data.

Most substances, whether visibly colored or not, have strong characteristic absorption bands in the infra-red. Hence studies in this region give much information regarding molecular structure. Infra-red absorption arises principally from intramolecular vibrations. Hence from infra-red spectra one might expect to obtain much information regarding force constants associated with the component parts of the vibrators. In accord with this expectation, it is possible to associate different regions of the spectrum with single, double, and triple bonds between such component parts of molecules, and to tell from the infra-red spectrum of a substance whether or not certain of its atoms are held together by single, double, or triple bonds. General problems associated with infra-red studies are those of deuterochemistry, tautomerism, isomerism, detection of hydrogen bonds, detection of association, resonance between two or more structures, oxidation and polymerization.

Absorption in the ultraviolet region occurs in certain so-called "chromophoric" groups—all unsaturated—for example, the benzene ring. Ultraviolet band absorption spectra are therefore very useful in detecting such substances as impurities.

Dr. Murphy's paper on the Raman effect began with a brief historical summary of the scattering of light, emphasizing the difference between Rayleigh scattering and Raman scattering. A theoretical description of the Raman effect based on the semiclassical dispersion theory of Kramers' and Heisenberg was supplemented by a quantum description in terms of energy levels.

The report was largely limited to a discussion of the spectra of a few simple diatomic and polyatomic gases. The complete Raman spectrum to be expected for a diatomic gas was indicated, and the observed rotational Raman spectrum of nitrogen was shown and compared with theory. It was made clear how the spectrum was used to determine the internuclear distance and the nuclear spin of the nitrogen molecule.

The mechanical motions of a polyatomic molecule are much more complicated than those of a diatomic molecule, but the motions may be resolved into several components, each corresponding to a definite frequency. Selection rules were discussed and slides were shown giving the normal vibrations of carbon dioxide, water, ammonia, methane, and benzene. In each case, some outstanding features of the spectrum and some unsolved problems were mentioned.

Finally it was emphasized that much work remains to be done in studying the simple polyatomic gases and that the results of such work, when combined with those of the other methods discussed in the symposium, will yield a more complete understanding of the geometry, force constants, and other properties of these molecules.

Joint Dinner

On Friday evening, February 23, at 6:15 o'clock, there was a joint dinner for members of the organizations and their guests at the Columbia University Men's Faculty Club, presided over by John Zeleny, President of the Physical Society.

Inter-Society Color Council

The sessions of the Inter-Society Color Council were held on Wednesday, February 21, and Thursday, February 22, at the Hotel Roosevelt. Abstracts of the papers presented at the technical and popular sessions are appended.

Contributed Papers

Simultaneous sessions of the Physical Society and the Optical Society of America for reading of contributed papers were held Friday afternoon and Saturday. The authors' abstracts of papers presented before the Optical Society of America are appended.

Meeting of the Board of Directors

The Board of Directors met on Thursday afternoon and evening, February 22. Excerpts from the minutes of the meeting are appended.

Arthur C. Hardy, *Secretary*

Minutes of the Fifteenth Meeting of the Directors of the Optical Society of America, Incorporated

NEW YORK, NEW YORK, FEBRUARY 22, 1940

BESIDES the transaction of routine business, the following items of general interest to members of the Society were taken up.

Announcement by President

The President reported the resignation of L. B. Tuckerman as Secretary of the Society as of December 31, 1939. Past President Gibbs then proposed the following resolution which was unanimously adopted:

"Whereas, Dr. L. B. Tuckerman assumed the duties of Secretary of the Optical Society of America on July 1, 1929; and

Whereas, he discharged these duties continuously until December 31, 1939; therefore,

Be it resolved that this Board hereby expresses its regret that he has found it necessary to tender his resignation and makes formal record of its thanks and appreciation for his many years of devoted service."

Announcements by Secretary

Results of letter ballots

1. Election of A. C. Hardy as Secretary for the term from January 1, 1940 to the annual meeting in October, 1940, *vice* L. B. Tuckerman, resigned.

2. Appointment of G. R. Harrison as Editor of Publications for a term from January 1, 1940 until the annual meeting of October, 1940, *vice* F. K. Richtmyer, deceased.

3. Appointment of William F. Meggers as Associate Editor of the Journal of the Optical Society of America to fill out the unexpired term of G. R. Harrison, resigned. This term will expire on December 31, 1943.

4. Appointment of Committees and Representatives

(a) Committees on Adolph Lomb Medal

To Formulate Conditions of Award

G. R. HARRISON, *Chairman*

BRIAN O'BRIEN — L. B. TUCKERMAN

To Supervise Preparation and Design

H. F. KURTZ, *Chairman* — I. C. GARDNER

CHARLES BITTINGER — H. E. IVES

To Recommend a Candidate to Receive the Medal in October, 1940

R. C. GIBBS, *Chairman*

A. C. HARDY — W. F. MEGGERS

RUDOLF KINGSLAKE — A. G. WORTHING

(b) Committee on Meetings and Programs for a term beginning March 1, 1940.

A. W. KENNEY, *Chairman*

R. S. ESTEY — G. E. GRANTHAM

L. V. FOSTER — DOROTHY NICKERSON

CLIFTON M. TUTTLE

(c) Committee on Membership

DOROTHY NICKERSON, *Chairman* — BRIAN O'BRIEN

G. R. HARRISON — C. F. J. OVERHAGE

A. W. KENNEY — F. H. PERRIN

G. S. MONK — LOUISE SLOAN

(d) Committee on Transfer from Associate to Regular Membership

W. E. FORSYTHE, *Chairman*

H. P. GAGE — R. KINGSLAKE

(e) Committee on Corporate Membership

W. B. RAYTON, *Chairman*

R. C. GIBBS — A. H. BENNETT

(f) Committee on Honorary Members

A. G. WORTHING, *Chairman*

J. W. BEAMS — E. C. CRITTENDEN

(g) Committee on Student Membership

BRIAN O'BRIEN, *Chairman*

R. C. GIBBS — W. B. RAYTON

G. R. HARRISON — R. A. SAWYER

(h) Advisory Committee on Progress Reports

R. C. GIBBS, *Chairman*

A. C. HARDY — A. G. WORTHING

(i) Auditors of Treasurer's Accounts

C. L. BAUSCH — C. W. FREDERICK

(j) Committee on Finance

H. F. KURTZ, *Chairman* — G. R. HARRISON

C. L. BAUSCH — L. A. JONES

L. A. DUBRIDGE — W. F. MEGGERS

(k) Committee on Colorimetry

L. A. JONES, *Chairman*

E. Q. ADAMS — D. B. JUDD

BLANCHE BELLAMY — E. M. LOWRY

CHARLES BITTINGER — M. LUCKIESH

E. C. CRITTENDEN — D. L. MACADAM

C. Z. DRAVES — S. M. NEWHALL

C. E. FOSS — DOROTHY NICKERSON

H. P. GAGE — BRIAN O'BRIEN

K. S. GIBSON — M. R. PAUL

I. H. GODLOVE — LOUISE SLOAN

A. C. HARDY — W. B. VAN ARSDEL

(l) Committee to Consider Publication of Colorimetry Report

G. R. HARRISON, *Chairman* — C. E. FOSS

H. A. BARTON — L. A. JONES

(m) Committee on Sponsorship of Committee Z-38, Photography, A. S. A.,
L. A. JONES, *Chairman* C. W. GARTLEIN
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(n) Representatives on the U. S. National Committee of the International Commission on Illumination,
FRANK BENFORD, *Chairman*
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(o) Representative on the A. S. A. Sectional Committee on Motion Pictures, Standards for—Z22,
B. H. CARROLL

(p) Representative and Alternate on the A. S. A. Sectional Committee on Safety Glass, Specifications and Methods of Test for—Z26,
E. D. TILLYER, Representative
N. F. BARNES, Alternate

(q) Representative on the Governing Board of the American Institute of Physics,
R. C. GIBBS

(r) Representative on the Council of the American Association for the Advancement of Science,
ELMER HUTCHISSON

Adolph Lomb Medal

The Committee appointed to Formulate the Conditions of the Award of the Adolph Lomb Medal submitted the following resolutions which were adopted unanimously:

"The Adolph Lomb Medal may be awarded by the Optical Society of America, not oftener than once in two years, to a person under thirty (30) years of age who shall have made a noteworthy contribution to optics."

"The Award shall be made to a medalist chosen by a two-thirds affirmative vote of the entire Board of Directors from nominees (or a nominee) recommended by an Adolph Lomb Medal Committee consisting of five regular members appointed for the purpose."

"When an Adolph Lomb Medal is awarded, it shall be presented at an annual meeting of the Society, preferably in a year in which there is no presentation of the Frederic Ives Medal."

Membership

The Secretary's report showed that since the last meeting of the Directors 4 members had died, 1 new member had been elected as of January 1, 1939, and 9 new members as of January 1, 1940.

Financial Status of the Society

The Treasurer presented the audited annual report for the fiscal year January 1 to December 31, 1939, noting that the financial condition of the Society continued to be satisfactory.

ARTHUR C. HARDY, *Secretary*

Program of Sessions for Contributed Papers

(Titles and Abstracts of Papers)

1. An Optical Device for Rapid Placement of an Aircraft on a Line between Two Distant Points. Brian O'Brien, *Institute of Optics, University of Rochester.*

To enable a pilot to place an airplane on a line between the sun and a ground station, a simple optical unit has been developed which has certain additional applications. A transparent triple mirror is formed by cementing three glass flats mutually perpendicular to each other, the joined edges being so cut that the boundary substantially vanishes when viewed in transmitted light. The triple mirror faces a fourth semi-transparent aluminized diagonal mirror, the axis of symmetry of the triple intersecting the diagonal mirror at 45°. A ray entering the system in either direction along this axis emerges along the perpendicular to this axis after reflection from the diagonal. An observer on the straight line joining two distant objects, viewing along the perpendicular to this line, thus sees the objects superimposed, one erect and one inverted, the superposition being undisturbed by any rotation of the optical system as a whole. The mirror system is mounted in a dust-tight housing of such dimensions that it can be held with rubber eye cup against one eye without obstructing the view ahead with the other. This permits maintaining the desired flight attitude of the airplane while observing the images of the two distant objects, which approach and pass through each other as the airplane crosses the line of sight. A real field of 22° is secured, and since the superposition is not affected by movement or rotation, the instrument has proven very satisfactory even in rough air. In the original form as used for solar work the ground station is seen erect without magnification at approximately full brightness while the inverted image of the sun is attenuated by a factor of 5×10^{-6} for comfortable observation. In a modified form with both images of equal brightness, the device has been applied to determine the distance of an aircraft above the top of an overcast by taking advantage of the depression of the horizon due to earth curvature.

2. Total Emissivity of Various Materials. B. T. Barnes, E. Q. Adams, and W. E. Forsythe, *General Electric Company, Nela Park, Cleveland, Ohio.*

The test objects were flat sheets, heated by contact with a brass vessel containing water at 100°C or with a copper plate heated by an electric table stove. Radiant flux from a central area of 6 cm² fell on a thermopile. Adequate shutters, diaphragms and a cooling bath were provided; water vapor and CO_2 were driven out by a stream of nitrogen. The calibration source was a blackbody chamber surrounded with boiling water. A brass mirror of special shape, maintained at 100°C, reflected radiation from a blackened enclosure to the thermopile. The emissivity at 100°C is given for various metal, glass and pressed-carbon samples and for metal sheets coated with various radiator paints. Most metal samples tarnished when held at 300°C. Only carbon, quartz and glass samples could be heated to 500°C without surface changes. The emissivities of these samples are given below.

	100°C	320°C	500°C
Average for four carbon samples	0.76	0.76	0.71
Fused quartz	.78	.80	.75
Corex-D glass	.80	.80	.76
Nonex glass	.82	.82	.78

The total heat loss from painted and unpainted containers at 100°C was determined. From these data and the emissivity values, the loss by conduction and convection in still air was found to average 0.05 watt/cm².

3. The Thermal Conductivities of Tungsten and Molybdenum at Incandescent Temperatures. Robert H. Osborn, *Hercules Powder Company.*

Worthing,[1] using an optical pyrometer method, found values for the thermal conductivity of incandescent tungsten which increased linearly with temperature. The present work was undertaken to check these values, and to extend his method to molybdenum. Results obtained for tungsten differed from those given by Worthing in that values obtained for the thermal conductivity decreased with increasing temperatures. This discrepancy is explained by the assumption that the use of certain empirical formulae deduced by Worthing to fit his data does not seem to be justified. Values found for tungsten range from 1.14 watts/(cm² K°/cm) at 1300°K to 1.03 watts/(cm² K°/cm) at 2000°K. Those for molybdenum range from 1.08 watts/(cm² K°/cm) at 1200°K to 0.67 watt/(cm² K°/cm) at 1900°K. In each case extrapolation of the function k *vs.* T (where k is the thermal conductivity and T is the absolute temperature) to room temperature yields values of k in reasonable agreement with those obtained by other workers. Resistivities obtained for tungsten were found to be in excellent agreement with values given by Forsythe.[2] Those for molybdenum were uniformly lower than the values given by Worthing.[3] This may be explained by differences in the purity of the wire in the two cases.

[1] A. G. Worthing, Phys. Rev. **4**, 535 (1914).
[2] W. Forsythe, J. Opt. Soc. Am. **24**, 114 (1934).
[3] A. G. Worthing, Phys. Rev. **25**, 846 (1925).

4. Tables of Planck's Radiation and Photon Functions.* A. N. Lowan and G. Blanch, *Work Projects Administration, New York City.*

Several recent papers on photon emission and blackbody radiation by A. G. Worthing and Frank Benford made it seem timely to compute Planck's functions of radiation and photon emission. Let $f(w)=[(\exp\ c_2/wT)-1]^{-1}$; $R_w=c_1w^{-5}f(w)$, $N_w=2\pi cw^{-4}f(w)$, where c_1 and c_2 are the well-known radiation constants, w is the wave-length (usually denoted by the Greek letter lambda), T is the absolute temperature and c is the velocity of light. Clearly, R_w is the intensity of blackbody radiation, and N_w is the correspond-

ing intensity of photon emission. Further, R_{0-w} and N_{0-w} denote the integral of $R_w dw$ and $N_w dw$, respectively, from zero to w. The authors computed three tables: Table I: The ratios $R_w/R_{w\,max}$, $N_w/N_{w\,max}$, $R_{0-w}/R_{0-\infty}$, $N_{0-w}/N_{0-\infty}$ for the following ranges and intervals of the argument wT $=0.050(0.001)0.100$; $0.100(0.005)0.400$; $0.400(0.010)0.700$; $0.700(0.020)1.000$; $1.00(0.050)2.00$ cm-deg. K. Table II: The functions R_w, N_w, R_{0-w}, N_{0-w} for $T=1000°$K and w ranging between 0.50 and 20.0 microns. (This table is coextensive with Table I.) Table III: N_w for 42 values of w ranging from 0.25 to 10.00 microns, and $T=1000$, 1500, 2000, 2500, 3000, 3500, and 6000°K. The following values of the constants were adopted, after consultation with H. T. Wensel and Lyman J. Briggs of the National Bureau of Standards: $c_1=3.732\times10^{-5}$ erg cm^2 sec.$^{-1}$; $c_2=1.436$ cm-deg. K. The tables are given to five significant figures, with first and second differences. There has also been included in the introduction to the tables a discussion about the number of significant figures which are reliable in various parts of the range, on the basis of the extent of uncertainty in the values of the constants c_1 and c_2, as well as a correction table for a change in c_2. The computations have been made by the Project for the Computation of Mathematical Tables, New York City, under the sponsorship of Dr. Lyman J. Briggs, Director of the National Bureau of Standards, with A. N. Lowan as the technical director.

* The present paper will appear in full in J. Opt. Soc. Am.

5. Clinical Blood Pharmacology After Treatment with X-Rays. DAVID I. MACHT, *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore.*

In a previous communication before this Society (February 19, 1938) the author reported the pharmacological results he obtained in studies on blood specimens taken from normal animals before and after their treatment with x-rays. Special phytopharmacological tests revealed that such samples contained a toxic substance appearing twelve hours or more after the subjects from whom they were taken had been exposed to x-rays. Discovery of this toxin suggested that it may play a role in the causation of Roentgen sickness. In the present paper the author reports the findings obtained in similar studies on blood specimens secured from human patients suffering from malignant and non-malignant affections, respectively. Blood specimens taken from all these cases after irradiation revealed a greater toxicity than that exhibited by the sera obtained from the same individuals before initiation of treatment. Of further interest were tests made on samples of blood taken from a dozen technicians employed in x-ray departments. The latter gave a marked phytotoxic reaction although the subjects from whom they had been obtained were in apparently good health.[1]

[1] D. I. Macht and M. B. Livingston, J. Gen. Physiol. **4**, 573 (1922); D. I. Macht, Protoplasma **27**, 1 (1937); Proc. Soc. Exper. Biol. & Med. **39**, 1 (1938); Am. J. Roentgenol. **41**, 709 (1939).

6. The *Komplextheorie* of Visual Sensation.* A. H. HOLWAY AND M. J. ZIGLER, *Wellesley College.*

Recent statements concerning the "new science of seeing" as opposed to the science of vision have completely overlooked one of the most outstanding attempts in the history of thought to formulate a comprehensive understanding of the facts of vision (=seeing). This formulation is the *Komplextheorie* of the late George Elias Müller. In formal outline the *Komplextheorie* is descriptive in nature in the same sense as the allegedly "new" proposals. Müller's theory, however, is much more comprehensive. From the time of its inception (*ca.* 1879) to the last decade (1934), this theory in its explanatory aspects has placed greatest emphasis upon variables within the organism, variables which occasion significant, detectable, and often measurable variations in visual sensation. Thus, to propose a "new science of seeing" on the ground that these variables have been overlooked by investigators of vision is not only to exhibit a marked lack of historical perspective but also to found the discipline on a basis which has no real existence. Müller proposed his theory about 1879, and continued to develop the fundamental ideas right up to his death in 1934. The present exposition is made with the sole purpose of acquainting investigators with the general principles of the theory as stated in Müller's latest works.[1]

* The present paper will appear in full in Psych. Rev.

[1] *Darstellung und Erklärung der verschiedenen Typen der Farbenblindheit, nebst Erörterung der Funktion des Stäbchenapparates sowie des Farbensinns der Bienen und der Fische* (Vandenhoeck and Ruprecht, Göttingen, 1924), pp. ix+216; *Über die Farbenempfindungen, Psychophysische Untersuchungen, Zeits. f. Psych. u. Phys. d. Sinnesorgane,* Erganzungsbander **17–18**, xviii+648 (1930); *Kleine Beiträge zur Psychophysik der Farbenempfindungen* (Barth, Leipzig, 1934), pp. iv+316.

7. The Spectral Sensibility of the Long-Eared Owl.* MAURICE HENRI PIRENNE[1] AND SELIG HECHT, *Laboratory of Biophysics, Columbia University.*

The owl's retina contains only rods, and its nocturnal habits have generally been correlated with this fact. Its sensibility distribution in the spectrum as determined by Piper in terms of retinal potentials follows that of other night birds and corresponds to the absorption and bleaching of visual purple in the spectrum. This whole picture was called into question by the report of Vanderplank that the owl is mainly sensitive to the infra-red of the spectrum. However, Vanderplank's work must be in serious error. First, Matthews and Matthews have shown that the far infra-red produces no retinal potential in the owl's eye. Second, we have now found that the near infra-red also produces no visual effect. We have further investigated the matter by determining the sensibility distribution of the owl's eye in the spectrum. Our method follows that of Vanderplank in using the iris contraction of the intact animal as a criterion of stimulating action. Exposure to different parts of a continuous spectrum isolated by Wratten and Corning filters shows not only that the owl is insensitive to the infra-red, but that its sensitivity to red and orange is low compared to its sensitivity to green and blue-green, and that its maximum sensitivity is near 515 mμ, much as is to be expected from the rod nature of its retinal elements. Calling 1.00 the energy at 533 mμ necessary to elicit a minimal contraction of the iris, then the necessary energy at 451 mμ is 3.27; at 490 mμ it is 1.18; at 576 mμ, 3.72; at 631 mμ, 39.5; at 652 mμ, 215.8; and at 683 mμ, 6223.0. Between 750 mμ and 2000 mμ even a relative energy content of 500,000 fails to elicit the slightest

contraction in the dilated pupil of the owl. The iris contracts strongly when the eye is exposed to ultraviolet of 360 mμ. Whether this corresponds to actual vision or only to the fluorescence of the ocular media remains to be decided.

* The present paper will appear in full in J. Gen. Physiol.
[1] Fellow of the Belgian American Educational Foundation.

8. Size of Pupil as a Variable Factor in Measurements of the Threshold. An Experimental Study of the Stiles-Crawford Phenomenon.* LOUISE L. SLOAN, *Wilmer Institute, Johns Hopkins Medical School.*

The studies of Stiles and Crawford and others[1] have shown that under certain experimental conditions the peripheral zones of the pupil show an apparent decrease in luminous efficiency. As a result, the brightness response of the eye is not directly proportional to the area of the entrance pupil. Under other experimental conditions, however, the different pupillary zones show an apparently equal luminous efficiency and the brightness response of the eye is therefore directly proportional to the area of the entrance pupil, as was previously believed to be true under all experimental conditions. The present study was undertaken to investigate the Stiles-Crawford phenomenon under experimental conditions which are directly applicable to determinations of the achromatic threshold, and in particular to the measurements obtained with the light sense tester devised by the author.[2] Experimental determinations of the achromatic threshold were made with a series of different sizes of pupil. Measurements were made at the fovea and in a paracentral region of the retina, with white, blue and red light. The data indicate that, within the accuracy of the measurements, the product, threshold times area of entrance pupil, is a constant. It is therefore possible to reduce all threshold measurements made with different sizes of pupil to a comparable basis if the diameter of the entrance pupil is known. A camera and auxiliary apparatus for photographing the pupil in the dark are described.

* The present paper will appear in full in Arch. Ophthal.
[1] W. S. Stiles and B. H. Crawford, Proc. Roy. Soc. **B112**, 428–450 (1932–33); W. S. Stiles, Proc. Roy. Soc. **B123**, 90–118 (1937); B. H. Crawford, Proc. Roy. Soc. **B124**, 81–96 (1937).
[2] L. L. Sloan, Arch. Oph. **22**, 228–251 (1939).

9. Experimental Determination of the Faithfulness of a Three-Color Reproduction. S. Q. DUNTLEY AND ARTHUR C. HARDY, *Massachusetts Institute of Technology.*

The adoption of certain resolutions by the I. C. I. in 1931 signalized the beginning of an extensive use of tristimulus values for the specification of color. This type of specification finds its most natural use in connection with problems arising in the field of three-color reproduction. Because each color of the original subject is reproduced by a mixture of three primaries, a spectroradiometric match between original and reproduction is too exacting a requirement. Instead, a subjective match under specified conditions must be accepted as the criterion of perfection. Testing the faithfulness of a color process by spectrophotometry and subsequent integration is a straightforward procedure when the original and the reproduction employ the same type of illuminant. For example, the color process may be adapted to exposure by tungsten light and projection by tungsten light. This paper deals largely with the procedure of testing when the color process is adapted for exposure to light of one quality and projection by light of another quality.

10. Warmth and Coolness of Colors. SIDNEY M. NEWHALL, *Johns Hopkins University.*

A circular chart of 50 color samples comprising the so-called Munsell "maxima," which are approximately equi-stepped throughout the hue circuit, was inspected individually by 297 observers. The instructions called for: (a) a decision as to which color suggested the greatest impression of thermal warmth, *viz.*, which color seemed warmest, (b) which color seemed coolest, and (c) any plausible reasons for the selections made. The results are as follows: (a) The "warmest" judgments show a minor mode in the violet at 420 mμ, but a strikingly major mode in the red-orange region at 610 mμ. (b) The "coolest" judgments exhibit no such marked mode, but range irregularly all the way from yellow through green and blue to purple. There are, however, some indications of peaking in the yellow around 572 mμ, the green at 552, and the blue at 476. (c) Outstanding natural sources of temperature stimulation which were mentioned, like the sun and fire, are largely confined to the red to yellow region, whereas prominent cool objects, like open water and shady vegetation, appear to range through the green, blue and into the purple. The relatively great hue-range covered by such perceptually cool objects provides opportunity for the psychological association of coolness with a relatively great range of hues. This may be the explanation of the striking disagreement concerning the "coolest" color.

11. Application to Dyes of the ISCC Method of Specification of Filters.* I. H. GODLOVE, *E. I. du Pont de Nemours & Co., Inc.*

The ISCC method[1] has been extended and applied to the rapid filing and reference to spectral transmission curves of various shapes and to identification of unknown dyes. This elaboration has been very briefly described.[2] The transmission scale is divided into 15 unequal intervals designated by digits and letters in a way easily remembered. These are read at nine wave-lengths; and the designation is used as an indexing tab. All solutions of known and unknown dyes are adjusted, without weighing, to a minimum of ten percent corrected transmission. A library of curves of soluble dyes on the American market having been built up, it is possible to identify unknown relatively pure dyes in a few minutes, using a few milligrams of material. The designations also permit very rapid location of dyes having a desired shape of spectral transmission curve, being useful thereby in picking out filter dyes and in similar problems. They facilitate study of the relation of light absorption and chemical constitution. With a little experience the shape of the curve is easily visualized from the designations. For example, the two following designate, respectively, a yellow with a very sharp "cut-off" and a nearly "neutral" dye:

339KAAAAA	"Pontacyl" Light Yellow GX
554544456	Du Pont Nigrosine WSJ powder.

Examples of curves and applications of the method will be given.

* The present paper will appear in full in J. Opt. Soc. Am.
[1] D. B. Judd, J. Opt. Soc. Am. **28**, 390–7 (1938).
[2] Inter-Society Color Council News Letter No. 28 (Dec., 1939).

12. Lighting for the Detection of Small Color-Differences. A. H. TAYLOR, *Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland.*

One of the commonest types of industrial color-matching in its broadest sense involves comparisons of colored objects differing only slightly in spectral reflection. The pairing of silk stockings in a hosiery factory is a good example. A theoretical treatment of this problem would indicate that the light best adapted to the detection of small color-differences of this character would be one rich in energy in the spectral region of maximum absorption by the colored object. This has been amply verified by a recent research in this laboratory. In a study of fading of dyed textiles by artificial light it was found that small amounts of fading of blue textiles were more easily detected under tungsten lamps than under fluorescent daylight lamps, but the fluorescent daylight lamp was superior when the textiles were pink or red. This study is being expanded to include a wide range of colored textiles and the results will be demonstrated.

BIBLIOGRAPHY: John C. Gehant, *"Thoughts on Color-Matching,"* Paint, Oil and Chem. Rev. (December 7, 1939), p. 9.

13. Applications and Accuracy of Three-Filter Photoelectric Colorimetry. RICHARD S. HUNTER, *National Bureau of Standards.*

Previous papers[1] have described the choice of three filters for approximate photoelectric tristimulus colorimetry with the G.E. barrier-layer photo-cell and incandescent source at 3100°K. These filters have been used with a multipurpose reflectometer:[2] (1) To derive approximate I.C.I. tristimulus specifications of surfaces, (2) To derive trilinear coordinates in a uniform-chromaticity-scale system, (3) To determine magnitudes of color difference (in NBS units[3]) between pairs of surface colors, (4) To measure whiteness of white and near-white surfaces, and (5) To measure yellowness of white and near-white surfaces. Steps in the computation of each of these quantities will be illustrated and sources of error will be noted. Chief in importance among the sources of error is failure of the source-filter-photo-cell combinations to duplicate spectrally the I.C.I. standard observer for colorimetry. Magnitudes of error from this source may be held to a minimum by choosing standards which are spectrally similar to the samples to be measured. When such standards are chosen, errors in the derivation of I.C.I. values are of the order of one-tenth the distances between the point representing the standard and those representing the respective samples on the (x,y)-diagram.

[1] R. S. Hunter, J. Opt. Soc. Am. **28**, 51 and 179 (1938).
[2] R. S. Hunter, J. Opt. Soc. Am. **27**, 225 (1937).
[3] D. B. Judd, Am. J. Psychol. **52**, 418 (1939).

ABSTRACTS OF PAPERS* PRESENTED BEFORE THE TECHNICAL SESSION ON SPECTROPHOTOMETRY IN THE PULP AND PAPER INDUSTRY OF THE INTER-SOCIETY COLOR COUNCIL

Jointly Sponsored by the Technical Association of the Pulp and Paper Industry

14. Introduction. Dialogue between Mr. Papermaker and Mr. Meter. D. B. JUDD AND L. C. LEWIS.

The color of paper may be adjusted to match a standard by addition of dye to the beater furnish. This adjustment may often be made successfully by visual comparison of trial sheets with the standard, provided the dyes used for the standard are also used in the beater. But if the dyes used for the standard are unknown a spectrophotometer may provide a more economical way to obtain a match than direct visual comparison.

15. Survey of Instruments—Spectrophotometers. K. S. GIBSON, *National Bureau of Standards.*

Recent progress in spectrophotometry in the visible spectrum has been largely along photoelectric lines. Most of these new instruments, however, have been designed for transmission measurements only, and are of little direct interest to the pulp and paper industry. Reference is made to various previous surveys of spectrophotometry and the present paper merely brings the subject up to date, with particular emphasis on reflection measurements. Visual spectrophotometric measurements have proved inadequate for the accurate colorimetric specification of white and near-white materials. The colors of such materials are importantly affected by small changes or differences of spectral reflection, differences that are of the order of magnitude of the uncertainties inherent in visual spectrophotometry. The photoelectric cell, on the other hand, is ideally adapted to the determination of small differences, and in apparatus designed on sound electrical and optical principles is capable of yielding spectrophotometric measurements that are both precise and accurate. All reflection spectrophotometers measure the apparent reflectance of a material relative to the apparent reflectance of a working standard, under certain fixed conditions of illumination and observation. The concept of apparent reflectance, the importance of considering the most desirable conditions of illumination and viewing, and the question of primary and secondary standards of apparent reflectance, are accordingly briefly considered.

* These papers will appear in the *Paper Trade Journal* and *Technical Association Papers.*

16. Survey of Instruments—Abridged Spectrophotometers. J. A. VAN DEN AKKER, *Institute of Paper Chemistry.*

"Abridged spectrophotometer" is defined as a spectrophotometer in which light filters passing relatively narrow wave-length bands are employed instead of a prism or

grating monochromatic illuminator. Instruments of this type may be classified according to their optical or spectral characteristics, geometry of illuminating and viewing of the sample, and method of measurement of light intensity or photometry. Similarly, instrumental discrepancies may be regarded as compounded of errors of the three classes: spectral, geometrical, and photometrical. The spectral characteristics of an instrument are those which depend upon wave-length of light. These characteristics determine the error in reflectance or transmittance intrinsic to the broad wave-length band passed by a filter. The spectral error depends also upon the spectral reflectance or transmittance curve over the range of wave-lengths passed by the filter. When this portion of the curve is a straight line, the effective wave-length for the instrument is that wave-length at which a true spectrophotometer gives the same result as that obtained by the abridged spectrophotometer. In comparing instruments of the same kind, it is convenient to consider spectral errors in terms of discrepancies in effective wave-length. "Geometry" of an instrument refers to the distribution of light energy over all angles of incident and reflected light, to the angle of incidence, and to the type of spatial arrangement for "viewing" the sample. Differences between the geometry of instruments of different design account for quite appreciable differences in reflectance, and such differences in instruments of the same kind are responsible for the geometrical error. The third component of instrumental error, namely, the photometrical error, depends upon the method of photometry employed. In routine control, where only precision and reproducibility are required, abridged spectrophotometers are in many cases adequate; they are not, however, sufficiently accurate for absolute color measurement. The spectral, geometrical, photometrical, and other characteristics of available abridged spectrophotometers are given.

17. Survey of Instruments in Use in the Pulp and Paper Industry.

This report will be compiled from answers to questionnaires, and will be published with the papers of this session.

18. Use of Instruments: In Pulp. R. S. HATCH, *Weyerhaeuser Timber Company.*

Both bleached and unbleached pulp may be considered as a raw material for further processing into finished articles of commerce. The problem of evaluating the color of pulp is one which involves the exact physical measurement of the color rather than the expression of color values in psychological terms. The best instrument and the instrument to which all physical measurements of color should be referred is an automatic recording spectrophotometer. Under certain conditions, where pulp is being produced from a single species, an abridged spectrophotometer may be used for general research purposes and a properly designed brightness meter may be used for manufacturing control. Brightness meters should be so constructed that commercial samples of the pulp itself can be directly measured without resorting to the making of special color sheets from the sample in question. Brightness meters in general could be improved by recommended changes in the illuminating system. In any kind of color measuring instrument in which photocells are employed, care must be taken to avoid dirt or foreign matter of any kind in that portion of the sample which is illuminated for test. Standard methods for the determination of dirt have been developed and are in common use; but in measuring the color of pulp, dirt should not be included since a true measure of the color is that of the mass of fibers themselves free from foreign matter.

19. Use of Instruments: In Beater Furnish. R. N. GRIESHEIMER, *Mead Corporation.*

Instrumental methods of controlling the color of beater furnishes are contrasted with the older method of visual control. Although the advantages of the instrumental methods are indisputable, neither method can be wholly successful in providing for color control of the finished sheet of dyed paper unless account is taken of certain machine variables that affect sheet color by influencing dye retention, etc. Important variables are the *p*H and freeness (refining treatment) of the to-wire stock. Instrumental methods are subdivided into empirical methods, and methods involving the absolute calculation of certain optical constants of the raw materials and finished sheet from either the Kubelka-Munk theory or the theory of Trichromatic Coefficients. The latter methods are principally of academic interest and have not met wide-spread use in the industry. Two empirical methods are outlined, both depending on the ability of a technical man to associate various dyestuffs with the shapes of their spectrophotometric curves, and the displacements of these curves with changes in dye concentrations. A particular instrumental method called the card index system is discussed in considerable detail. A program for indexing variations in reflectance at certain wave-lengths with weight of dye producing these changes for a given furnish is set up. It is then indicated how these data, considered with other data taken on the effect of important machine variables, can be used for predicting the color of the finished sheet. A double integrating sphere reflectometer and a time-saving wet pulp sampling procedure are briefly described as tools found useful in applying the card index system. In conclusion, general aspects of the problem are discussed including considerations of start-up losses due to off-color, color tolerances, and the selecting of a method and instruments to fit a particular mill's requirements.

20. Use of Instruments: In Uncoated Paper. MYRL N. DAVIS, *Kimberly-Clark Corporation.*

This discussion is limited to the use of spectrophotometers and colorimeters in the design and control of "white," uncoated papers. Experience has shown that a working estimate of the apparent "whiteness" of paper can be obtained by measurement of reflectance with light of 458 millimicrons wave-length. Instrumentation is available and widely used for making such single measurements on paper samples in controlling the uniformity of paper being manufactured. Hue of the paper is still controlled visually in all but a few paper mills. It is possible, by use of the Guerivic,

Kubelka and Munk, Smith theory of the optical properties of diffusely reflecting materials, to determine scattering and absorption coefficients for the pulp and pigment of which paper is manufactured and by use of these coefficients to predict the reflectance and opacity of papers made from any proportions of these raw materials. Examples are given of such predictions for machine made papers, the optical coefficients having been obtained from simple hand made papers. The effect of supercalendering on opacity and color is discussed. Exact quantitative estimates of the effect of supercalendering are not yet possible.

21. Use of Instruments: In Coated Paper. WILLIAM J. FOOTE, *Consolidated Water Power and Paper Company.*

By means of spectral reflectance curves, dyestuffs may be identified either in coated or uncoated papers and rough quantitative estimations made. In addition, spectral reflectance curves may be used to specify the color of standard grades, to act as a guide in color matching in general, and particularly in the case of matching the color of base sheet and coating of tinted whites, and to indicate tolerances. A more precise method of specifying standard colors and tolerances consists of using chromaticity diagrams based on the specification of color by the method proposed by the International Commission on Illumination in 1931. By the use of one additional measurement (either R_0 or $R_{.98}$ at any chosen wave-length) and calculations involving the Kubelka and Munk relationship, valuable information is obtained on the fundamental optical coefficients (scattering and absorption) of coatings made up with various types of pigments. This permits a study of the effects of different raw materials and the successive steps in the process of manufacture on color, gloss, and opacity of the finished product. The relation of the physical measurements, brightness (G.E.R.M.) and visual efficiency (Y), with visual "brightness" and "whiteness" and the possibility of there being an optimum color for white printing papers are briefly discussed.

ABSTRACTS OF PAPERS PRESENTED BEFORE POPULAR SESSION OF INTER-SOCIETY COLOR COUNCIL

22. Highlights of Color Reproduction History.

This is a presentation in radio style recreating the scenes of the first color printing, LeBlon's development of the mezzotint process, Maxwell's suggestion of photographic methods to reproduce the colors of objects, and the application of the principles of LeBlon and Maxwell by F. E. Ives in his halftone screen printing process. Following the highlights of past centuries, a typical production problem of recent times is presented. The difficulties due to unstandardized steps in the various processes are portrayed and the introduction of standard methods is made. The presentation ends with a look at the future.

23. Color Reproduction Fundamentals. F. L. WURZBURG, JR., *Interchemical Corporation Research Laboratories.*

This is a review of the principles of the various additive and subtractive methods of color reproduction from both the objective and subjective standpoints. It will be shown how the development of the sciences of colorimetry and spectrophotometry have recently contributed materially to a better understanding of the theoretical requirements which any truly accurate and automatic method of color process must fulfill. The simplification of the artist palette by the utilization of the principles of three-color mixture so long used in the processes of automatic color reproduction will be explained.

24. Science Visits the Artist. WILLIAM L. LONGYEAR, *Department of Advertising Design, Pratt Institute.*

This is a report of the findings of an artist-industrial designer who visited the summer art colonies to study the reaction of a trichromatic palette. Demonstrations were given at art association meetings and the opinions of the established artists as well as the students were obtained. Paints made with the trichromatic palette will be shown.

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